Space Shuttle Solid Rocket Booster (SRB) Recovery System Sandia Laboratories Progress Report March 1974 Through February 1975

MASTER

Sandia Laboratories

SAND75-0077
Unlimited Release
Printed February 1975

SPACE SHUTTLE SOLID ROCKET BOOSTER (SRB) RECOVERY SYSTEM
SANDIA LABORATORIES PROGRESS REPORT
MARCH 1974 THROUGH FEBRUARY 1975

Sandia Laboratories
Albuquerque, New Mexico 87115

Work Performed Under NASA
Defense Purchase Request (DPR)
H-3247B

Project Engineer: D. F. Wolf

Editor: L. L. Alpaugh

Contributors

Section	Title	Authors
1	Preliminary System Evaluation	D. F. McVey D. F. Wolf
2	Drogue Deployment Analysis	W. D. Sundberg D. F. Wolf E. J. Meyer
3	Parachute Inflation Analysis	D. F. Wolf
4	Parachute Stree Analysis	S. D. Meyer
5	Drop Test Program	L. T. Holt H. R. Spahr D. F. Wolf

FOREWORD

Support provided by Sandia Laboratories to NASA Marshall Space Flight Center in the preliminary design and analysis of the SRB Recovery System during the period March 1974 through February 1975 is documented in this report. Because of the informal nature of the majority of the working meetings and discussions between Sandia and NASA personnel, it is not possible to document all of the information transferred during this period. The report does assemble in one package the results of studies and evaluations specifically requested by NASA and previously presented in Working Group Meetings. A report format has been chosen which hopefully minimizes the effort required to change briefing viewgraph material into a readable report.

TABLE OF CONTENTS

BLANK PAGE

SUMMARY

The initial task requested by NASA was a preliminary evaluation of the SRB recovery system baseline as it existed in March 1973. As a result of this evaluation, Sandia confirmed that the NASA selection of a ribbon drogue and cluster of three ribbon mains provided the best system for a state-of-the-art development program. In addition, a series of the baseline parachute designs revealed that acceptable design practice was being followed in most cases, resulting in reasonable parachute weights. Several areas requiring further study were defined. The baseline drogue deployment method (by a tether attached to the ejected nose cap) was objected to, and a computer study was initiated to complement NASA wind tunnel tests. Independent calculation (by Sandia) of parachute inflation loads and parachute canopy stresses was recommended. A review of drop test requirements was also undertaken.

The computer study, wind tunnel test results, and past experience in developing large ribbon parachutes all indicated that the baseline drogue deployment method was not acceptable. An alternate method using a large (15 to 20 ft) pilot chute and heavy line ties was suggested.

Predicted inflation loads for the early baseline drogue were significantly higher than those used to design the chute and attachment structure. A higher porosity drogue which provided the required drag and acceptable load levels (226,000 pounds) was recommended. Predicted inflation loads (135,000 pounds) for the main chutes agreed closely with previous NASA predictions.

A stress analysis of the parachutes confirmed that the desired design margins existed in both drogue and main chutes. Horizontal ribbons were found to be overdesigned in both chutes, suggesting the possibility significant weight savings. A need for more detailed load-strain data for the particular nylon materials being used in the designs was identified.

The need for a drop test program as an absolute requirement in the parachute development program was stated. A review of candidate drop test aircraft revealed that the B-52 Mother Ship provided the capability desired for simple and reliable drop tests. Simulated drop test inflation loads showed that design load, and in many cases overload, conditions could be achieved using a 50,000 pound test vehicle.

SUMMARY

- NASA CHOICE OF A RIBBON DROGUE AND THREE RIBBON MAINS FOR THE SRB RECOVERY SYSTEM IS BEST FOR A STATE-OF-THE-ART DEVELOPMENT PROGRAM

- NASA PARACHUTE WEIGHTS ARE REASONABLE FOR DESIGN FACTOR USED AND STANDARD PARACHUTE DESIGN PRACTICE

- DEPLOYMENT OF THE SRB DROGUE BY A TETHER ATTACHED TO THE EJECTED NOSE CAP IS UNACCEPTABLE

- THE DROGUE SHOULD BE DEPLOYED BY A 15 TO 20 FOOT PILOT CHUTE

- MAXIMUM PREDICTED INFLATION LOAD FOR REDESIGNED 20 PERCENT POROSITY DROGUE IS 226,000 LB.

- MAXIMUM PREDICTED INFLATION LOAD FOR A MAIN CHUTE IS 135,000 LB.

- MATERIALS SELECTED FOR THE SRB DROGUE AND MAIN CHUTE, HAVE ADEQUATE STRENGTH FOR THE DESIGN LOADS AND DESIGN FACTORS SPECIFIED

- SIGNIFICANT WEIGHT SAVINGS MAY BE POSSIBLE IN THE HORIZONTAL RIBBONS

- MORE DETAILED MATERIAL CHARACTERIZATION DATA ARE REQUIRED FOR AN ACCURATE STRESS ANALYSIS

- A DEVELOPMENTAL DROP TEST PROGRAM FOR THE SRB RECOVERY SYSTEM IS ESSENTIAL

- THE B-52 "MOTHER SHIP" DROP TEST AIRCRAFT AND A 50,000 LB. DROP TEST VEHICLE SHOULD BE USED

- DESIGN LOADS FOR ALL SINGLE CHUTE STAGES AND THE MAIN CHUTE CLUSTER FIRST STAGE ARE POSSIBLE WITH THE RECOMMENDED TEST METHOD
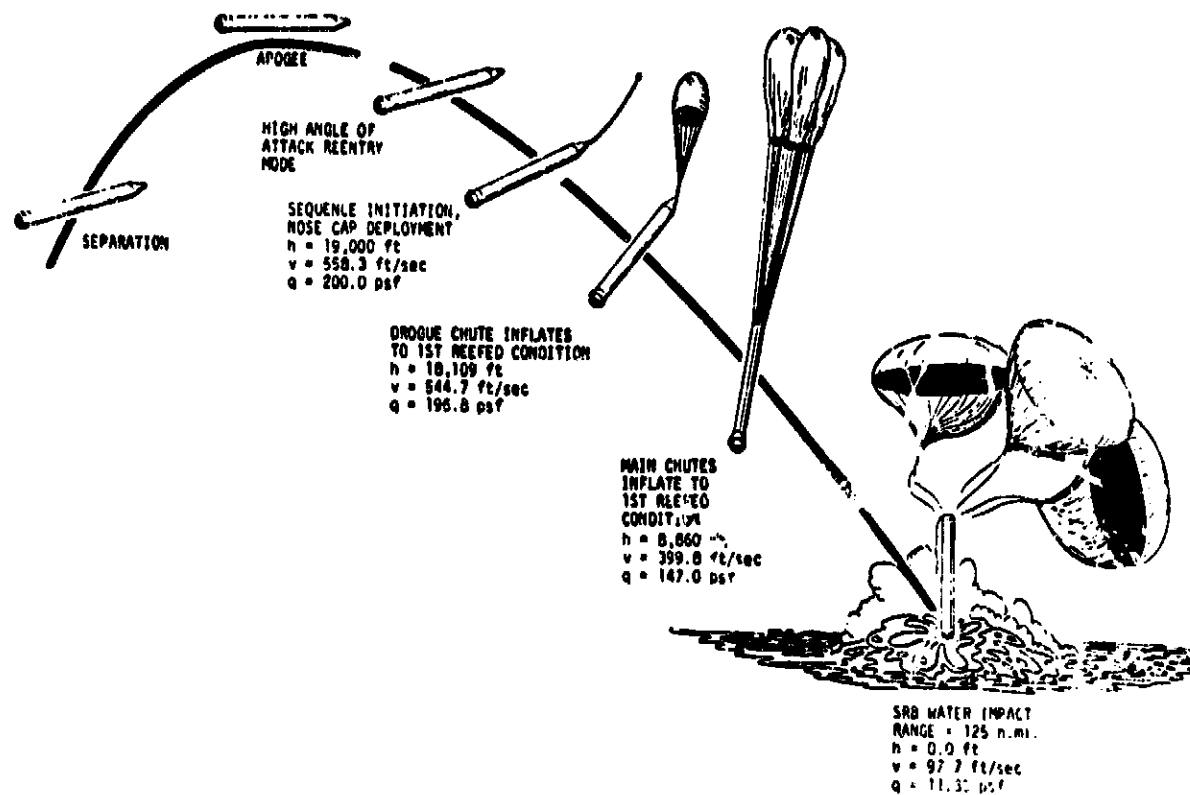
SECTION 1
PRELIMINARY SYSTEM EVALUATION

BLANK PAGE

TYPICAL SOLID ROCKET BOOSTER (SRB) TRAJECTORY

The SRB recovery concept specified by NASA as of March 1974 is illustrated on the adjoining page. After separation the SRB follows a ballistic path until reentry. Upon reentry it stabilizes in a near-broadside attitude, with the large broadside drag providing an initial deceleration stage. At an altitude of 10,000 feet a drogue chute is deployed which turns the SRB to a tail first attitude and slows it to the proper speed for main chute deployment. Main chutes are then deployed which slow the SRB to a water entry speed of about 100 ft/sec.

TYPICAL SOLID ROCKET BOOSTER (SRB) TRAJECTORY

APOGEE

HIGH ANGLE OF
ATTACK REENTRY
MODE

SEPARATION

SEQUENCE INITIATION,
NOSE CAP DEPLOYMENT
h = 19,000 ft
v = 558.3 ft/sec
q = 200.0 psf

DROGUE CHUTE INFLATES
TO 1ST REEFED CONDITION
h = 18,109 ft
v = 544.7 ft/sec
q = 196.8 psf

MAIN CHUTES
INFLATE TO
1ST REEFED
CONDITION
h = 8,860 ft
v = 399.8 ft/sec
q = 147.0 psf

SRB WATER IMPACT
RANGE = 125 n.mi.
h = 0.0 ft
v = 92.7 ft/sec
q = 11.32 psf

SRB RECOVERY SYSTEM BASELINE

The SRB recovery system baseline specified by NASA as of March 1974 consisted of a one-drogue and three-main system. The 54-foot drogue was extracted from the front of the broadside SRB by the ejected nose cap. A single reefed stage for the drogue was used to turn the SRB to a tail-first attitude, and the full-open drogue provided the proper main chute deployment conditions. A cluster of three 104-foot main chutes was then deployed by the drogue. Two reefed stages were used to minimize main chute inflation loads, and the full-open cluster provided the desired water entry speed of 100 ft/sec.

SRB RECOVERY SYSTEM BASELINE

- TAIL FIRST WATER ENTRY

- 100 FPS VERTICAL & 45 FPS HORIZONTAL WATER ENTRY VELOCITY

- 1 - 54-FOOT DROGUE CHUTE WITH 1 DISREEF

- 3 - 104-FOOT MAIN PARACHUTES WITH 2 DISREEFS

- NOSE CAP EXTRACTS DROGUE CHUTE

- DROGUE CHUTE EXTRACTS MAIN CHUTES

- LOSE NOSE CAP

- SAVE NOSE FRUSTUM

- RECOVER & REFURBISH ALL PARACHUTES

- DESIGN REQUIREMENTS: 200-Q AT 19,000 FEET

- RETAIN CHUTES AT WATER IMPACT

NASA CHOICE OF A RIBBON DROGUE WITH THREE RIBBON MAINS IS BEST FOR A "STATE-OF-THE-ART" DEVELOPMENT PROGRAM

Based on the data and reasons given in the accompanying charts, it is felt that the design objectives of the baseline design concept chosen by NASA for recovery of the solid rocket booster (SRB) can be met with a state-of-the-art development program.

Ribbon parachutes have been widely used where high strength, ruggedness, and reliability are required. There are large amounts of data available on ribbon parachutes which ranging in size from several inches in diameter to 130 feet in diameter. The basic parachute is well under-stood.

Use of a drogue parachute to initially stabilize and orient an unstable or improperly aligned vehicle is standard practice. In general, a drogue is smaller and lighter than the final stage system. Thus, it is easier to deploy in that the forces required to accelerate the parachute to a deployment velocity sufficiently high to prevent line sail and entanglement are lower than the forces required for the main system. Since the drogue would also have fewer and shorter lines than most mainstage systems, the probability of damage (line burn, etc.) is less. The cost of refurbishment would probably also be lower since there would be less material to replace and the bulk would be reduced.

A three parachute system is superior to an N chute or one chute system. Three chutes are geometrically more stable than either 2 or 4. There is more applicable three chute data available. It is easier to interconnect reefing to control lead-lag loading for three chutes than for four or more. The individual chutes in a three chute cluster are within the state-of-the-art in terms of size and fabrication.

NASA CHOICE OF A RIBBON DROGUE WITH THREE RIBBON MAINS IS BEST FOR
A "STATE-OF-THE-ART" DEVELOPMENT PROGRAM

- MOST CONSISTENT WITH LOW COST - LOW RISK SINCE MORE
  APPLICABLE DATA ARE AVAILABLE
- RIBBON CHUTES OF THE APPROPRIATE SIZE AND STRENGTH
  RANGE HAVE BEEN BUILT AND FLOWN
- RIBBON CHUTE MORE RUGGED AND CAN BE DESIGNED FOR
  REFURBISHMENT
- NO DROGUE SYSTEM INTRODUCES MORE UNKNOWNS
- THREE CHUTE MOST GEOMETRICALLY STABLE IF CORRECT
  TRAIL DISTANCE USED
- SYSTEM COMPLEXITY AND DEPLOYMENT PROBLEMS INCREASE
  AS NUMBER OF CHUTES INCREASES
- BASED ON SANDIA EXPERIENCE BARO DEPLOYMENT BEST
  CHOICE FOR RECOVERY INITIATION

1 X 180 FT VS 3 X 104 FT MAIN PARACHUTES

In comparing a single 180-foot diameter final stage system with a system of three 104-foot diameter parachutes, the major factors in favor of the three chute system are that the single chute is out of the present state-of-the-art (i.e., it is larger in diameter than any previously built and flown system) and the single chute would be more likely to become entangled with the booster at water impact.

1 X 180 FT VS 3 X 104 FT MAIN PARACHUTES

- GENERAL
  - 180 FT MAIN CHUTE WEIGHING 4000 LB IS CONSIDERABLY BEYOND PRESENT STATE-OF-THE-ART

- WEIGHT/VOLUME
  - PROBABLY LITTLE DIFFERENCE

- FABRICATION COST
  - SINGLE MAIN REQUIRES MORE SPECIAL EQUIPMENT BUT PROBABLY CHEAPER FOR SAME NUMBER OF SYSTEMS

- PACKING COST
  - LITTLE DIFFERENCE

- HANDLING
  - SINGLE MAIN MORE DIFFICULT

- MATERIALS
  - PROBABLY LITTLE DIFFERENCE

- SYSTEM COMPLEXITY
  - CLUSTER HAS MORE COMPONENTS

- DEPLOYMENT
  - 180 FT MAIN WOULD REQUIRE SIGNIFICANTLY MORE DEPLOYMENT DEVELOPMENT AND WOULD PROBABLY EXPERIENCE MORE DEPLOYMENT DAMAGE

- INFLATION
  - SINGLE MAIN HAS LONGER INFLATION TIMES, HAS HEAVIER REEFING LINES WHICH MAY REQUIRE REEFING CUTTER DEVELOPMENT, MAY REQUIRE MULTIPLE REEFING LINES

  - CLUSTER HAS NONUNIFORM INFLATION PROBLEMS

- FLIGHT TESTING
  - PROBABLY CANNOT PROPERLY LOAD FINAL STAGE OF 180 FT MAIN

  - GREATER UNCERTAINTIES IN NUMBER OF TESTS REQUIRED FOR 180 FT MAIN

- RETRIEVAL
  - SINGLE MAIN WOULD LAND ON TOP OF BOOSTER DURING A LARGE FRACTION OF FLIGHTS - RETRIEVAL COULD BE IMPRACTICAL UNDER THESE CONDITIONS

- REFURBISHMENT
  - SAME COMMENTS AS FOR FABRICATION, PACKING, AND HANDLING

- REUSE
  - MAY NOT BE POSSIBLE IF MAIN CHUTE LANDS ON TOP OF BOOSTER

SYSTEM WEIGHT

Accurate assessment of the system weight requires development of data to define required design and material degradation factors. These factors, described in detail later in the report, are probably the major unknowns in determining the system weight. Given these factors and the proper material property data, currently available analytical tools can be used to compute loads and stresses for system design.

Analysis of the NASA proposed design indicates the weight estimates are probably conservative (e.g., design factors are quite large).

SYSTEM WEIGHT

   ACCURATE ASSESSMENT OF PARACHUTE WEIGHTS REQUIRES BENCH TESTS
      TO EVALUATE DESIGN FACTORS

   STRUCTURAL DESIGN CODES WILL PERMIT MORE ACCURATE MATERIAL
      SIZING AND MORE BALANCED DESIGN

   ACCURATE MATERIAL PROPERTIES (LOAD vs STRAIN; DYNAMIC EFFECTS)
      ARE NOT AVAILABLE AND MUST BE OBTAINED

   CURRENT NASA WEIGHTS ARE REASONABLE FOR DESIGN FACTOR USED
      AND STANDARD PARACHUTE DESIGN PRACTICE

GENERAL COMMENTS - PARACHUTE CONSTRUCTION

Comments on parachute construction details are shown on the accompanying chart. Some of the points are amplified in the following discussion.

It is recommended that standard ribbon parachute gore section construction be used. This may permit easier repair if the gores are joined by several rows of "nonlock" stitching in that the stitching may be easily removed and a gore removed for repair.

It is recommended that a "second vent" be used for porosity control. If all radials are carried to the vent, the resulting geometric porosity in the vent area will be quite low. If at least every other radial is terminated at a second vent one half to three quarters of the way from the skirt to the actual vent, a better porosity distribution, will be obtained. This will help to prevent blowing the crown of the chute during the initial inflation phase. The vent band for the second vent can replace the intermediate reinforcing bands.

Increasing the suspension line length from $1.0\ D_0$ results in an increase in drag as shown by the chart on page 1-15. About a 17 percent increase in drag can be achieved by increasing the line length to $1.5\ D_0$. A similar drag increase can be obtained by increasing the main chute trail distance as shown in the chart on page 1-17. From these data, it appears that parachute drag can be optimized as a function of dimensions, weight, and riser lengths.

GENERAL COMMENTS PARACHUTE CONSTRUCTION

USE GORE SECTION
CONSTRUCTION

ELIMINATE INTERMEDIATE REINFORCING BANDS
ON MAIN CHUTES

USE SECOND VENT FOR POROSITY CONTROL; POROSITY
SHOULD BE NEARLY CONSTANT ALONG CHUTE

DO NOT EXTEND LINES OVER TOP. DESIGN FOR
REQUIRED STRENGTH FROM RADIAL RIBBONS;
POSSIBLE USE OF CONNECTOR LINKS

USE EXTREMELY STRONG SKIRT AND VENT BANDS

MAIN CHUTE LINE LENGTHS $1.5 \ D_0$ FOR OPTIMUM
DRAG - TRADE-OFF vs WEIGHT

MAIN CHUTE TRAIL $1.6 - 1.7 \ D_0$

INTERCONNECTED MAIN CLUSTER BEST TO MINIMIZE
LEAD-LAG INFLATION

ELECTRONIC REEFING CUTTERS ALSO MINIMIZE
LEAD-LAG

STRUCTURAL ANALYSIS WILL ALLOW MORE OPTIMUM
CHUTE DESIGN

FULL OPEN DRAG COEFFICIENT VS POROSITY
20° CONICAL RIBBON PARACHUTES

Parachute Full open drag coefficient vs geometric porosity is shown. The variation in drag coefficient based on constructed diameter is shown for several line lengths. The data were taken on 3-foot diameter ribbon parachutes in the LTV low speed wind tunnel. [1-1]

[1-1] Sandia Corporation Pressure and Disreefing Test of Model Parachutes in the Vought Systems Division Low Speed Wind tunnel, LSWT 445, 3 Sept. 1974.

FULL OPEN DRAG COEFFICIENT VS POROSITY
20° CONICAL RIBBON PARACHUTES
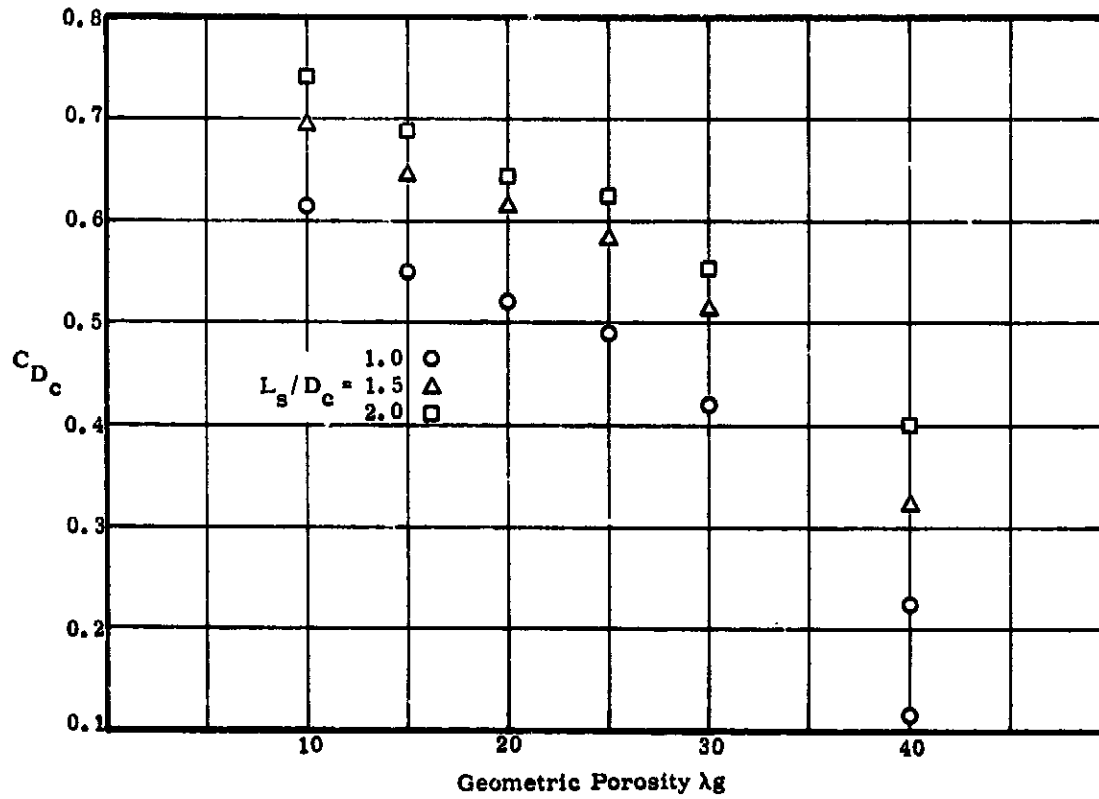
RATIO OF CLUSTER DRAG TO THREE TIMES SINGLE DRAG VS TRAILING DISTANCE IN CHUTE DIAMETERS

The effect on cluster drag of increasing the line lengths of three parachutes in cluster is shown. The system consisted of three 1.5-foot diameter constructed ribbon parachutes. Plotted is the ratio is the ratio of the cluster drag coefficient (based on constructed diameter) to the single parachute drag coefficient for a line length of $1.9 D_c$. It is noted that the drag increases as l_s/D_c increases to about 1.8 or 2.0.

Ref: Sandia Corporation Pressure and Disreefing tests of Model Parachutes in the Vought Systems Divisions Low Speed Wind Tunnel, LSWT445, 3 Sept. 1974.

RATIO OF CLUSTER DRAG TO THREE TIMES SINGLE DRAG VS TRAILING DISTANCE IN CHUTE DIAMETERS

Parachutes $C_{D_c} = 0.586$, N = 8, $\lambda g = 20\%$

Y-axis: $\dfrac{C_{D_{c\ell}}}{3C_{D_c}}$

X-axis: L_s/D_c

C_{D_c} used for normalizing
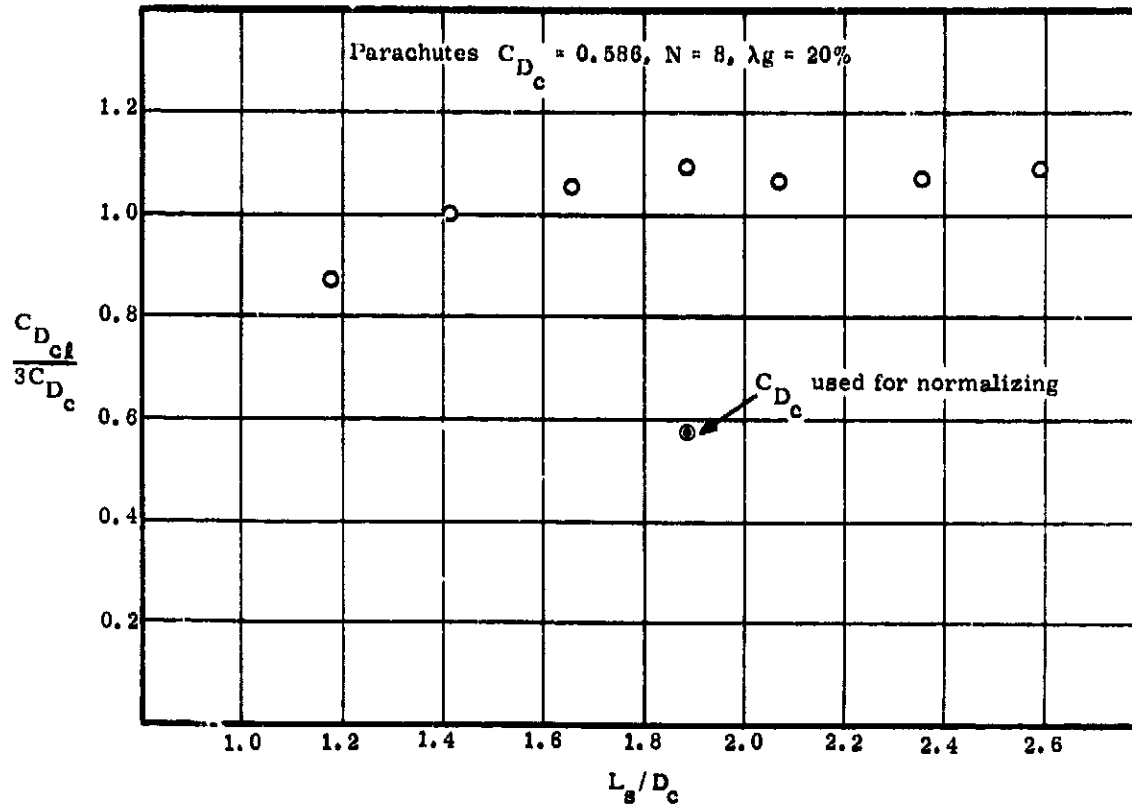
DROGUE DEPLOYMENT AND MAIN CLUSTER DEPLOYMENT

The accompanying chart summarizes comments on the parachute deployment technique.

This problem has been analyzed extensively, and the results are detailed later in the report. The results confirm the comments made on the chart.

DROGUE DEPLOYMENT

> NOSE CAP DRAG IS NOT MUCH GREATER THAN DRAG FROM THE DROGUE
>> BAG. PILOT SYSTEM SHOULD EXERT 20 TO 30 G ACCELERATION ON
>> BAG TO PREVENT LINE SAIL AND ASSURE GOOD CHUTE LAYOUT.
>> WITH 76 FT TETHER SNATCH LOAD AT 200 fps ΔV WILL BE VERY
>> HIGH. PROBLEM UNDER ANALYSIS
>
> POSSIBLE STABILITY PROBLEMS WOULD RESULT IN LINE BURN AND
>> WHIP AND NONUNIFORM LAYOUT OF CHUTE. PROBLEM UNDER ANALYSIS
>
> MUST USE ABRASION RESISTANT (STEEL) RISER SYSTEM TO ATTACH
>> DROGUE TO BOOSTER
>>> PREVENTS BOOSTER ABRASION OF DROGUE LINES
>>> EQUALIZES DROGUE LINE LOAD
>
> BEST DESIGN FROM STANDPOINT OF PREDICTABILITY AND RELIABILITY
>> WOULD BE TO EJECT NOSE CAP AND DEPLOY DROGUE WITH AN 18 TO
>> 20 FT PILOT CHUTE
>
> MAY BE ACCEPTABLE TO DEPLOY DROGUE FROM PILOT CHUTE EXTRACTED
>> NOSE CAP

MAIN CLUSTER DEPLOYMENT

> DROGUE AS PILOT CHUTE LOOKS ACCEPTABLE. GIVES CORRECT LEVEL OF
>> ACCELERATION ON MAIN BAGS AND FRUSTUM.RAPID DEPLOYMENT
>> ALLOW LESS TIME FOR BOOSTER TO DESTABILIZE
>> USE 4 REEFING LINE CUTTERS PER LINE

DESIGN FACTORS

As previously discussed, the Design Factors have a significant impact on the system weight. Early evaluation of these factors by laboratory and other ground tests is required in order to accurately design the system. The accompanying chart summarizes typical design and material degradation factors and gives typical values that are estimated based on knowledge available to Sandia.

The abrasion, fatigue, and water exposure factors probably are the least known at this time. It is felt that the only good abrasion data will be obtained from evaluation of actual SRB recovery systems since this factor depends so heavily upon actual useage and handling history. Fatigue can be evaluated in a laboratory by a parametric study in which typical strain cycles for various component parts of the parachutes are reproduced. Water exposure data also can be obtained in the laboratory. Probably the main damage in salt water exposure occurs when salt crystallizes upon drying. DuPont data (1-2, -3, -4, -5) indicate that the effect of salt solution on nylon strength is minimal (i.e., < 10 percent reduction). These data based on liquid salt and do not include possible damage to the fabric structure by salt crystals.

As noted in DuPont data (1-5-6), light exposure has a large effect on nylon strength. The exact changes in a given webbing or other fabric structure would have to be determined experimentally since the total strength change is a function of the material thickness. There are also dyes such as DuPont Capracyl Yellow NW that greatly improve the ultraviolet resistance of nylon.

Reference 1-5 also points out that nylon is degraded quite severely by rusting iron or steel. Thus, care must be used to insure that the suspension lines and risers that contact steel fittings are protected.

[1-2] The Chemical Resistance of DuPont Nylon Dupont Bulletin N-30, July 1955.

[1-3] Resistance of Fibers to Aqueous Solutions of Various Salts, DuPont Technical Information, Bulletin X-216, April 1967.

[1-4] Fish Nets and Twines of DuPont Nylon, DuPont Technical Information, Bulletin X-168, Jan. 1964.

[1-5] Properties of Ropes of Dacron and DuPont Nylon, DuPont Technical Information, Bulletin X-226, Feb. 1969.

[1-6] Light and Weather Resistance of Fibres, DuPont Technical Information, Bulletin X-203, April 1966.

DESIGN FACTORS

SAFETY FACTOR	- (l.5) STANDARD CARGO AND SPECIAL WEAPON.
JOINT, LOOP, SEAM	- (0.8 - 0.9) USE GROUND TEST DATA AND PROBABILITY ANALYSIS. CAN BE FUNCTION OF NUMBER OF JOINTS AND SERIOUSNESS OF FAILURE.
ABRASION	- (0.9 - 0.95) ONLY GOOD DATA WILL COME FROM EVALUATION OF ACTUAL FLIGHT AND RECOVERY DAMAGE DUE TO DEPLOYMENT AND HANDLING .
FATIGUE	- (0.9 - 0.95) CAN BE DETERMINED FROM GROUND TEST. SHOULD BE EVALUATED AS SOON AS POSSIBLE. RIBBONS WILL PROBABLY REQUIRE LOWER NUMBER DUE TO FLUTTER. PROPER DESIGN OF MATERIAL MAX STRAINS CAN MINIMIZE.
WATER	- DU PONT DATA INDICATE LITTLE EFFECT. CONFIRM WITH GROUND TEST.
ULTRA VIOLET	- (0.95) PROBABLY MORE IMPORTANT THAN WATER. ESTIMATE OF EXPOSURE TIME REQUIRED. SOME DATA AVAILABLE.
RE USE FACTOR	- PROPER ASSESSMENT OF ABRASION, FATIGUE, WATER, AND U-V FACTOR COVER RE USE.
CONVERGENCE	- INCLUDED IN DESIGN. SHOULD NOT BE A DESIGN FACTOR.
CLUSTER AND NON-UNIFORM LOAD	- CAN BE ASSESSED ANALYTICALLY.

RECOMMEND THAT GROUND TESTS TO EVALUATE MATERIAL DEGRADATION
FACTORS BE STARTED AS SOON AS POSSIBLE SINCE SYSTEM WEIGHTS
AND MATERIAL SPECS ARE INFLUENCED SO GREATLY BY THESE VALUES.

SUGGESTED SET OF DESIGN FACTORS FOR THE DROGUE (D) AND MAIN (M) PARACHUTES

The accompanying chart illustrates a suggested set of design factors for the SRB drogue (D) and main (M) parachutes. Note that different factors are suggested for each chute and for different components of each chute. The safety factor varies from component to component based on the consequences of failure of that component relative to system performance. As previously noted, the material factors are <u>estimates</u> and need to be investigated in the laboratory.

SUGGESTED SET OF DESIGN FACTORS FOR THE SRB DROGUE (D) AND MAIN (M) PARACHUTES

FACTOR		RISERS	LINES	RADIALS	RIBBONS	VENT, SKIRT BANDS	REEF LINES
1. SAFETY	D	--	1.5	1.5	1.5	1.0	1.0
	M	1.0	1.5	1.5	1.5	1.0	1.0
2. JOINT, LOOP, SEAM	D	0.3	0.5	0.5	0.8	0.5	0.5
	M	--	0.95	0.95	1.0	1.0	1.0
3. ABRASION	D	--	0.95	0.95	0.95	1.0	1.0
	M	1.0	0.95	0.95	1.0	1.0	1.0
4. FATIGUE	D	--	0.95	0.95	0.90	0.95	1.0
	M	0.95	0.95	0.95	0.90	0.95	1.0
5. WATER	D	--	0.98	0.98	1.0	0.98	1.0
	M	0.98	0.98	0.98	1.0	0.98	1.0
6. ULTRA VIOLET	D	--	0.95	0.95	0.95	0.95	1.0
	M	1.0	0.95	0.95	0.95	0.95	1.0
7. COMBINED MATERIAL FACTOR, ROWS 2 - 6	D	--	1.32	1.32	1.48	1.26	1.11
	M	1.34	1.32	1.32	1.48	1.26	1.11
8. LOAD VARIATION SIDE DEPLOYMENT OR CLUSTER	D	--	1.0	1.0	1.0	1.0	1.0
	M	1.25	1.25	1.25	1.25	1.25	1.25
DESIGN FACTOR (1) X (7) X 8	D	--	2.0	2.0	2.2	3.8	3.3
	M	5.0	2.5	2.5	2.7	4.7	4.2

FAILURE RESULTS IN SYSTEM FAILURE
STANDARD-CARGO AND SPECIAL WEAPON
KEEP WET

SECTION 2

DROGUE DEPLOYMENT ANALYSIS

BLANK PAGE

BOOSTER TURN-AROUND BY DROGUE CHUTE

A dynamic analysis of the solid rocket booster recovery system was performed in the areas of booster dynamics and drogue chute deployment.

The booster dynamics analysis includes two particular events: (1) turnover of the booster at drogue chute deployment and (2) booster dynamics between drogue chute release and main chute deployment. The basic analysis tool used for the booster dynamic analysis was a six-degree-of-freedom-trajectory computer code with an option of modeling a drag area (drag coefficient x reference area) acting at an arbitrary attachment point. There are five significant features to this particular option. First, the velocity at the attachment point is not assumed to be the same as the velocity of the center of mass of the body (i.e., the booster) but is rather $\vec{V}_{cg\ body} + \vec{\omega}_{body} \times \vec{r}_{attachment\ point}$. With the distance to the attachment point being approximately 80 feet from the booster center of gravity, the "$\omega \times r$" term causes the velocity at the attachment point to be significantly different from the velocity at the center of gravity of the booster. Second, the force at the attachment point is calculated based on the dynamic pressure calculated from the velocity at the attachment point. Third, the direction of the force is assumed parallel to the velocity at the attachment point, implying an instantaneous response of the attached parachute. Fourth, moments are created about the CG of the booster ($\vec{r}_{attachment\ point} \times \vec{F}_{attachment\ point}$) because the force does not act at the CG. Fifth, the drag area may vary as a piecewise linear function of time.

In the turnover analysis at drogue deployment, the initial conditions of the booster for the trajectory study are:

Altitude = 18,000 ft

Dynamic pressure = 200 lb/ft^2

Velocity (at booster cg) = 543 ft/sec vertically down

Orientation: x axis (centerline) horizontal

Various angular rates of the booster were assumed for the initial condition in the trajectory study, including all rates zero, pitch rate of 30^0/sec, yaw rate of 30^0/sec, and roll rate of 45^0/sec.

Physical properties, which were used, in the analysis, for the booster, are:

Mass = 154,240 lb$_m$

Roll moment of inertia = 1.55 x 10^5 slug - ft^2

Pitch and yaw moment of inertia = 8.8 x 10^6 slug - ft^2

Parachute attachment point = 77 ft ahead of cg

The aerodynamic coefficients for the booster, which were used in the trajectory calculations, were axial force coefficient, C_A, normal force coefficient, C_N, static pitching moment coefficient, C_m, and pitch damping moment coefficient, C_{mq}, and were assumed to be only functions of mach number and total-angle-of-attack. Values for the coefficients were taken from two NASA MSFC memos: (1) S&E - AERO-AA-73-82, "Revised Shuttle SRB Reentry Static Aerodynamic Characteristics" November 12, 1973 and (2) S&E-AERO-AN-73-45, "SRB Entry Dynamic Stability Derivatives" August 3, 1973. The assumed drag area ($C_D S$) for the 54 ft dia ribbon drogue chute was as follows:

| Time	$C_D S$
0.0 (linear increase)	0.
0.927	1008.
12.927	1008.
(linear increase)	
13.070	1260.
t > 13.070	1260.

Two items about the aerodynamics should be noted. First, the assumed drag area vs time for the drogue chute does not include "spikes" which would occur due to overinflation and oscillations in parachute diameter. The effect on the total impulse on the booster, and thus the angular motion, due to ignoring the "spikes" is small; however, peak loads cannot be accurately predicted without including them. The second item is simply that the parachute aerodynamics overwhelm the booster aerodynamics when the 54 foot diameter drogue chute is attached.

For all the initial angular rates which were tried, the resulting booster angular motion was nearly planar. The worst case (i.e., highest amplitude) for angular motion was the case where the booster was initially pitching nose down at 30°/sec. Plots of the resulting motion are shown opposite. The late-trajectory-time oscillations ($\sim 2^\circ - 4^\circ$) which were predicted do not include any angular motion which could be induced by parachute angular oscillations. Resulting parachute forces predicted by this analysis have not been included here because a more detailed analysis including overinflation and parachute oscillations was done subsequent to this analysis which gives more accurate parachute loads.

BOOSTER PITCH RATE HISTORY AFTER DROGUE CHUTE DEPLOYMENT
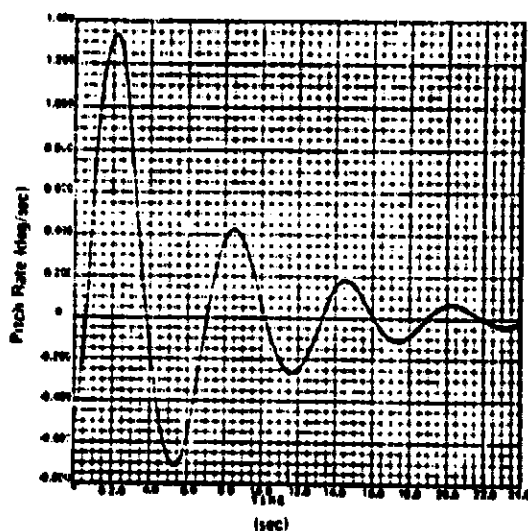
BOOSTER ANGULAR MOTION HISTORY AFTER DROGUE CHUTE DEPLOYMENT (ALTERNATE PEAKS REPRESENT NEGATIVE ANGLES)
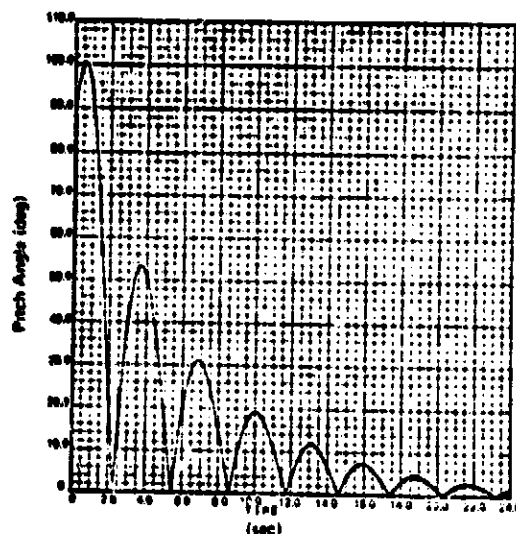
VELOCITY HISTORY OF PARACHUTE ATTACHMENT POINT ON BOOSTER FOLLOWING DROGUE DEPLOYMENT
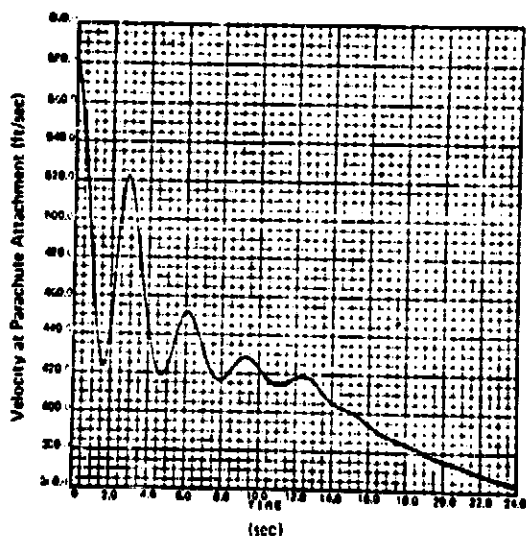
VELOCITY HISTORY OF BOOSTER CENTER OF GRAVITY FOLLOWING DROGUE DEPLOYMENT
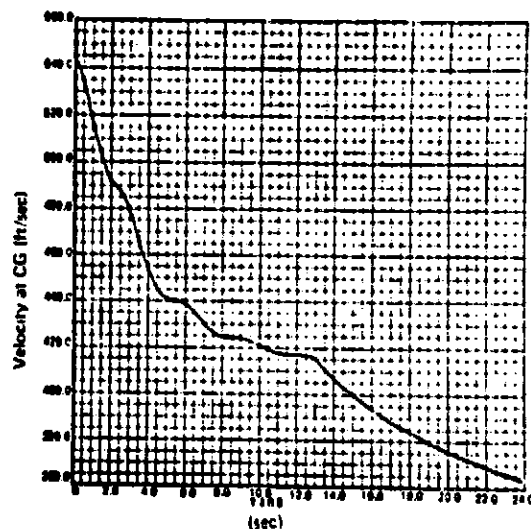
BOOSTER MOTION AFTER DROGUE RELEASE

The second part of the booster dynamics analysis was the dynamics between release of the drogue chute and deployment of the main chutes. For this analysis, the initial conditions are obtained from the results of the turnover analysis of the booster for the case with all initial angular rates zero. The release of the drogue chute is assumed to take place 21.3 seconds after drogue deployment at an altitude of 8860 feet. The same mass properties and aerodynamics characteristics for the booster were used. The analysis shows that turnover from the basically nose up condition is very slow; however, the increase in velocity, and thus dynamic pressure, is very rapid and it is very important that the main chutes be deployed as rapidly as possible, suggesting that the drogue chute be used as the pilot chute for deploying the main chutes. The graphs opposite show the booster pitch angle vs time from drogue release and dynamic pressure vs time from drogue release.

BOOSTER MOTION AFTER DROGUE RELEASE

BOOSTER PITCH ANGLE HISTORY FOLLOWING DROGUE RELEASE

Time from drogue release, sec.
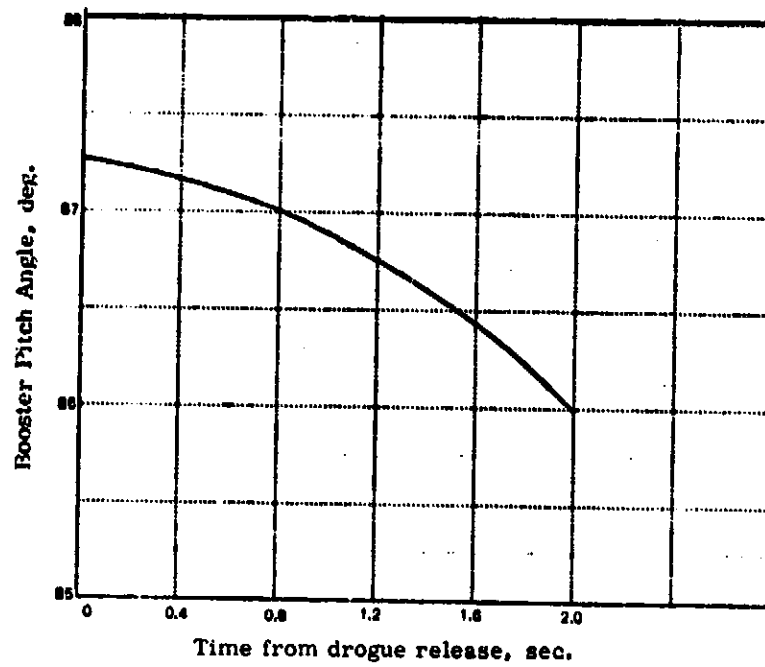
BOOSTER DYNAMIC PRESSURE HISTORY FOLLOWING DROGUE RELEASE

Time from drogue release, sec.
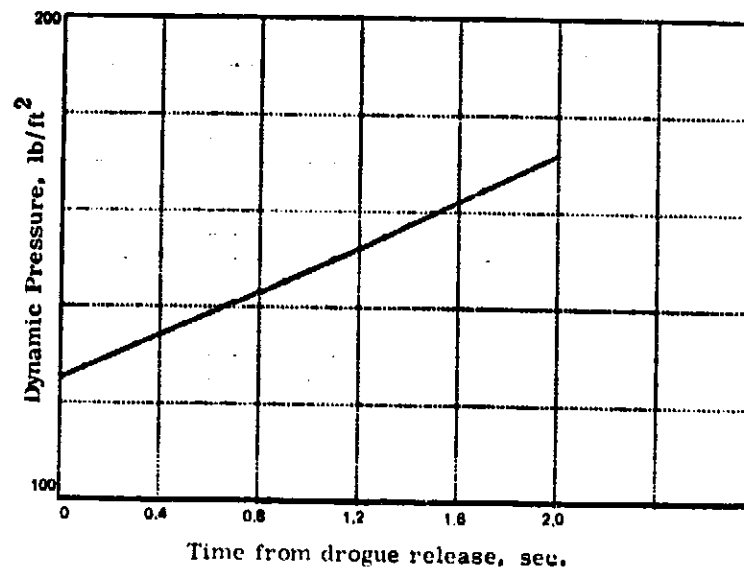
The first event in the NASA baseline design for the drogue deployment is the ejection of the nose cap from the SRB. A dynamic analysis of this event was performed to verify the 80 ft/sec ejection velocity necessary to avoid contact with the drogue bag during ejection as shown in NASA MSFC memo S&E-AERO-DD-5-74, "SRB Nose Cap Ejection Velocity Requirements" March 4, 1974 and Northrop Services, Inc. memo 9250D-74-7, "Nose Cap Separation" February 26, 1974.

The analysis tool which was used was a two body trajectory computer code, with each body having the full six degrees of freedom. The code which was used was an extension to the SANAF six-degree-of-freedom trajectory code. In the extended version, the secondary body (Body B) has its position calculated with respect to the primary body (Body A) to increase the accuracy of the relative position, rather than calculating absolute positions of each and determining the difference.

Careful attention to the initial conditions for Body B and Body A has been given. The velocity of the two bodies does include the $\vec{\omega} \times \vec{r}$ term due to change in CG position and angular rates. An ejection velocity and an angular tipoff rate may be applied to Body B.

The primary difference between this analysis and the analysis in the two previously mentioned memos is that this analysis does model the movement of the SRB. The SRB characteristics used here are the same as those used for the booster turnover analysis. The nose cap properties which were used are:

> Mass = 202 lb_m
>
> Pitch/yaw moment of inertia = 36.3 slug - ft^2
>
> Roll moment of inertia = 18 slug - ft^2 (assumed)
>
> Center of gravity = 25.3 in forward of nose cap base

The aerodynamic coefficients were taken from NASA MSFC memo S&E-AERO-AA-73-24, "Subsonic Aerodynamic Characteristics of the SRB Nose Cap," April 30, 1973. Aerodynamic interference between the nose cap and the booster was neglected on both nose cap and booster.

Initial conditions for the analysis were the same as those for the booster turnover analysis but without the roll rate. In all cases the nose cap was assumed to be ejected axially with an 80 ft/sec impulsive ejection velocity. The worst case of those examined was the initial nose down pitch rate of 30 deg/sec. Even in this case, contact would not occur between the nose cap and drogue pack.

NOSE CAP EJECTION

DISTANCE BETWEEN NOSE CAP
CG AND BOOSTER CG AFTER
EJECTION
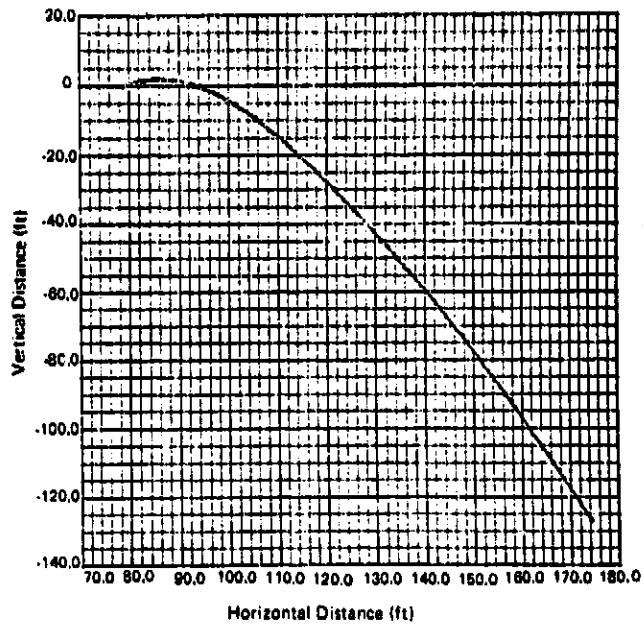
PITCH ANGLE VS HORIZONTAL
DISTANCE FOR NOSE CAP
EJECTION
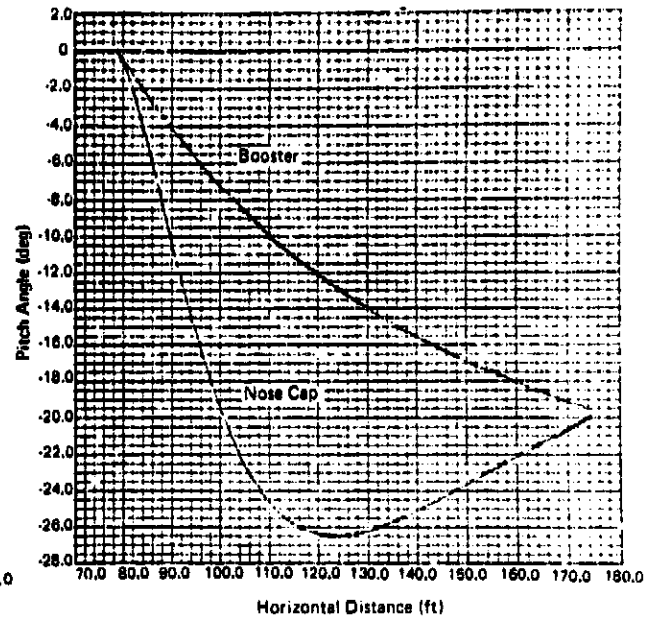
SEQUENCE FROM NOSE CAP EJECTION MOVIE
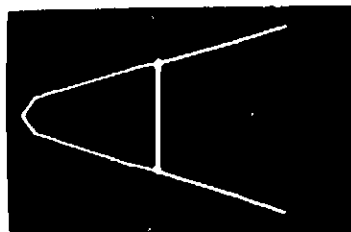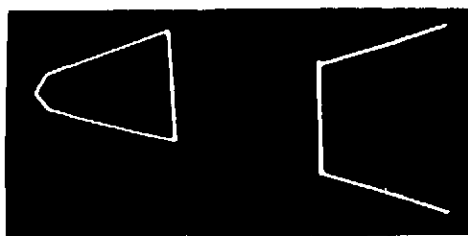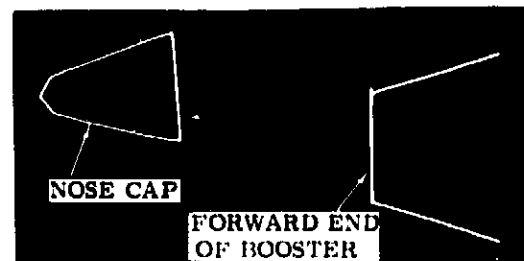

TIME = 0.0000 SECONDS
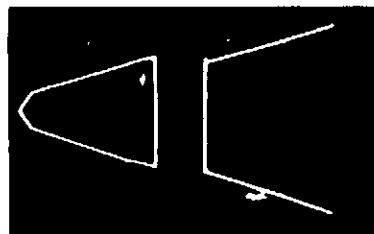
TIME = 0.0250 SECONDS
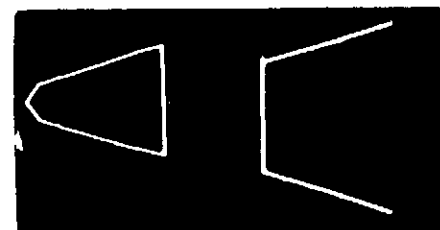
TIME = 0.0500 SECONDS


TIME = 0.0750 SECONDS

TIME = 0.100 SECONDS

TETHERED NOSE CAP

The 2nd area of analysis in the drogue deployment analysis was the dynamics of the tethered nose cap and the dynamics of the drogue pack. The same two 6DOF-body trajectory code was used as the primary analysis tool, with the addition of an elastic line connecting the two bodies at arbitrary attachment points. Body B has been modeled to allow line deployment from it, with mass loss, mass property changes and an averaged line tie force during deployment. The drag area at an attachment point was included as an option in the version of the code.

The idealized base line concept invisioned the nose cap acting as a steady drag device for deploying the drogue parachute. This somewhat governed the capabilities incorporated in the computer code, i.e., a drag area (nose cap as a steady drag device) attached to a 6 DOF-body (drogue pack deploying line) attached to another 6 DOF-body (the SRB). Although such a trajectory was computed, analysis of the nose cap dynamics on the end of a tether quickly showed that the tether load on the drogue pack could not be treated as a steady drag force. A calculation of 200 pound nose cap ejection, with a 40K tether attached to a fixed drogue pack, was performed in determining tether loads for snatching the nose cap. A plot of the tension in the tether vs time for this case is shown opposite. It shows that after the first peak in tension, the line goes completely slack and is followed by a second peak and tension oscillations.

TETHERED NOSE CAP

TENSION IN 40,000 LB TETHER FOR DEPLOYMENT OF A 200 LB NOSE CAP

2-
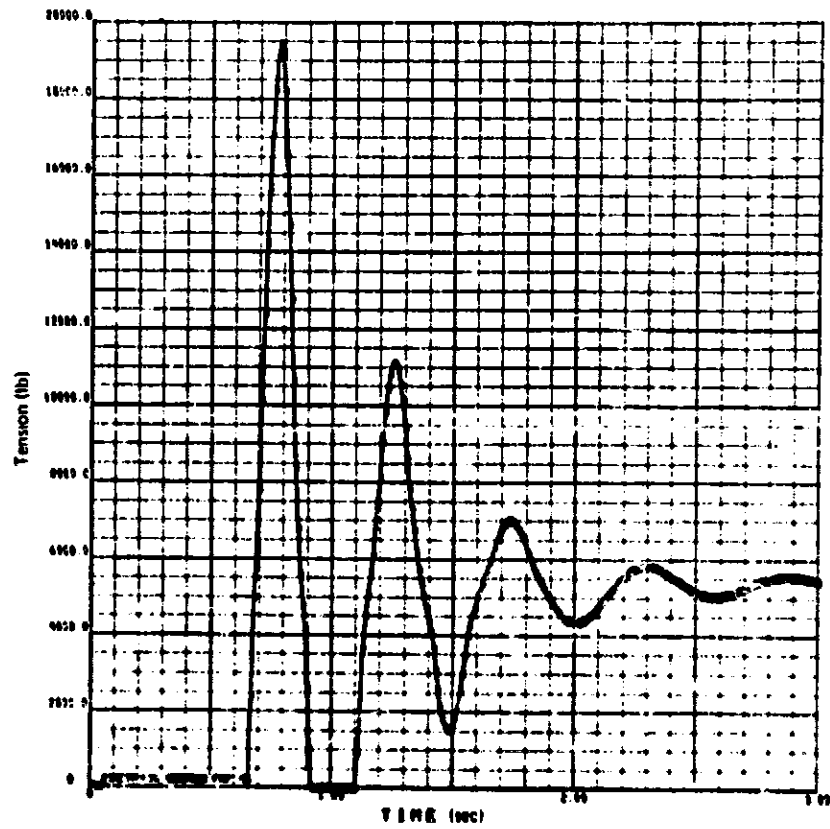
DROGUE BAG EXTRACTION BY NOSE CAP

The more realistic case is with the tether (60K rated) attached to a deployable drogue pack. This was modeled as much as possible; the limitation is that mass could not be deployed from the drogue pack because the two 6 DOF-bodies were the 300 pound nose cap and the drogue pack. The initial motion predicted by this model is correct, but it would begin to be in error when significant mass should have been deployed from the drogue pack. This modeling showed that during the time when deployment would occur (t < 1.5 sec) only two tension pulses would occur in the tether, giving a drogue gun type deployment rather than a steady drag force deployment. The two tension pulses also induce some severe angular motion to the drogue pack.

DROGUE BAG EXTRACTION BY NOSE CAP

TENSION IN TETHER - METHOD 1
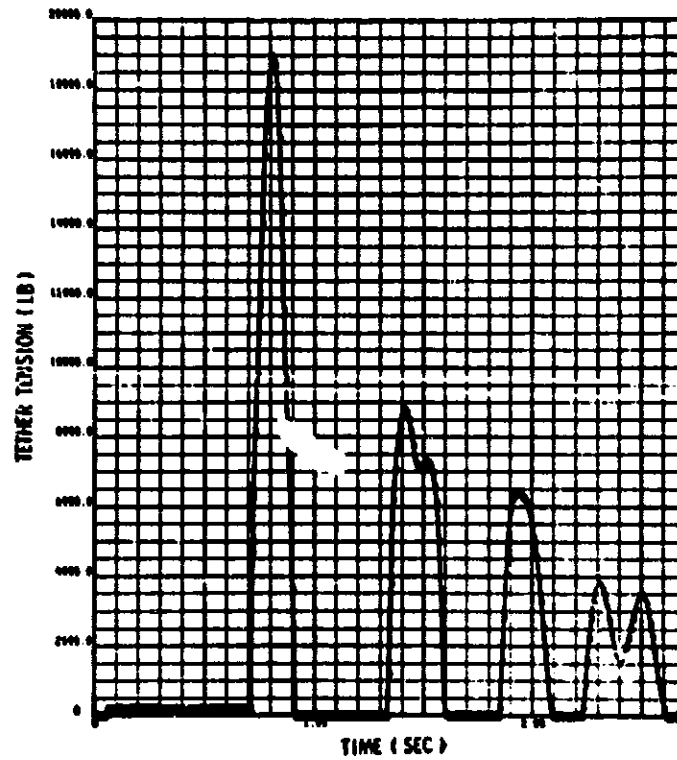
NOSE CAP AND DROGUE PACK PITCH ANGLES
METHOD NO. 1
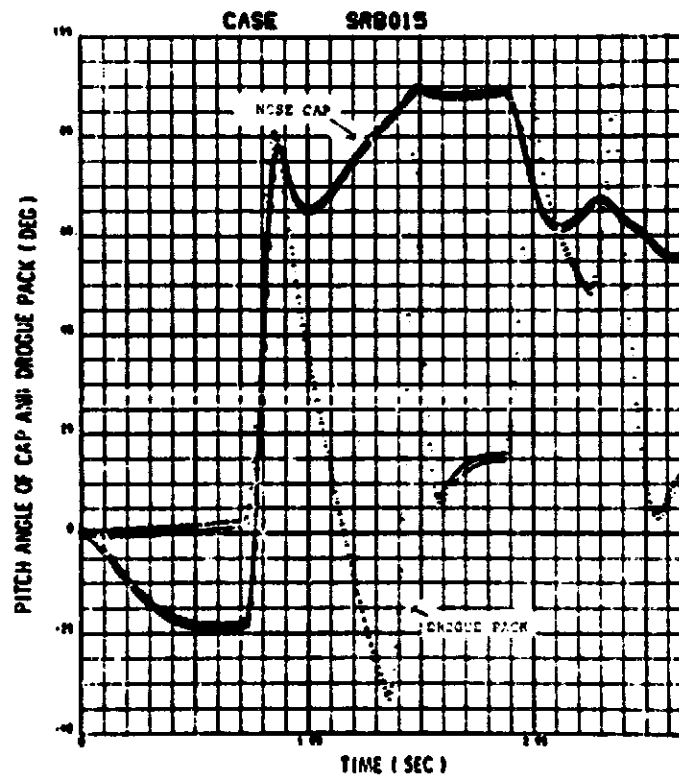
DROGUE BAG EXTRACTION BY NOSE CAP (continued)

The significance of the angular motion is shown opposite in which some selected frames from a movie are presented which show the motion during deployment of the drogue using the nose cap. Also notice the angle of crossflow to which the suspension lines are subjected during deployment.

TIME = 0.6750

TIME = 0.7371

NOSE CAP CENTERLINE

TETHER (WITHOUT AERO FORCES)—

TIME = 0.8078

DROGUE SUSPENSION LINES (WITHOUT AERO FORCES)

TIME = 1.2578

DROGUE BAG CENTERLINE

SRB CENTERLINE

TIME = 1.5373

PILOT CHUTE EXTRACTION OF DROGUE BAG

An alternate deployment method was also briefly investigated. This method used a pilot chute to deploy the drogue chute from the 200 pound nose cap with the nose cap being pulled off and not ejected. The pilot chute was assumed to be equivalent to an 18-foot ribbon parachute. Varying mass properties for the nose cap with the deploying drogue chute were calculating assuming a constant density, conical frustrum drogue pack of varying length. The resulting angular motion of the nose cap is shown opposite, using the same booster initial conditions.

PILOT CHUTE EXTRACTION OF DROGUE BAG

NOSE CAP ANGLE-OF-ATTACK - METHOD NO. 3
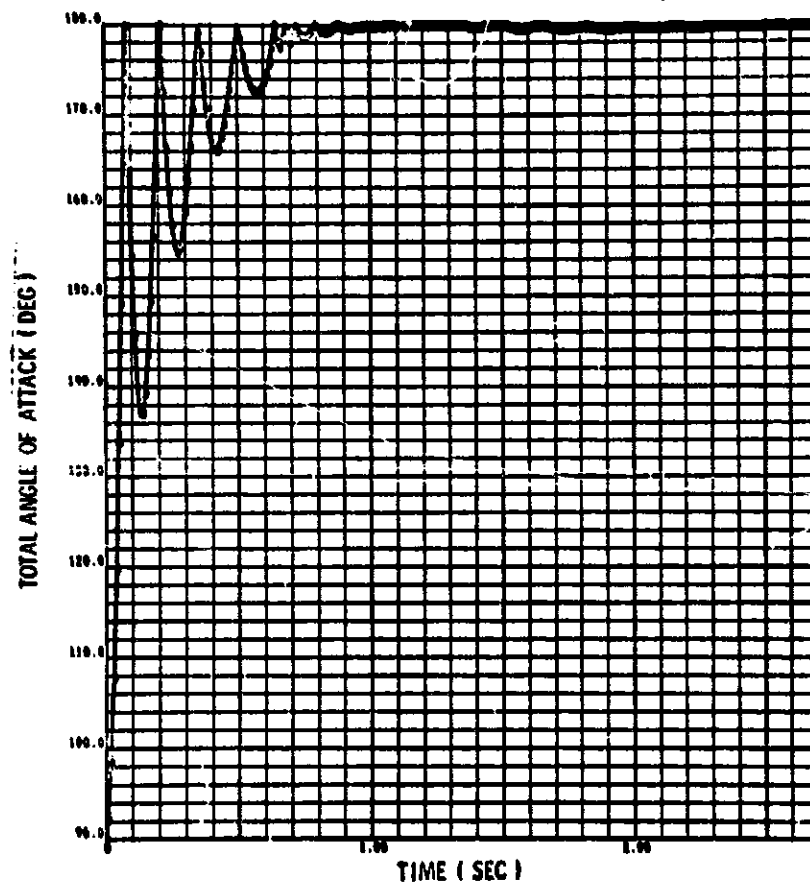
DYNAFLATE SIMULATION OF DROGUE DEPLOYMENT

A second type of analysis of the drogue deployment was performed using the Dynaflate finite-element axisymmetric parachute deployment and inflation computer code. This model includes both canopy and suspension lines. Of particular interest in this analysis was line sail and snatch load. Aerodynamic forces are included on the suspension lines as the crossflow drag. Line ties are also modeled. A realistic initial condition, of lines folded across the deployment bag, was used. Two concepts were modeled with Dynaflate: (1) the deployment with a nose cap (drogue gun type) and (2) deployment from the nose cap assuming an 18 foot pilot chute. Both concepts were modeled assuming a zero angle of attack of the parachute during deployment. The nose cap deployment concept was modeled, up to the point of the canopy starting out of the bag, with 45° crossflow angle. A comparison of the results between the two methods is as follows.

	Tethered Nose Cap Concept	Deploy from Nose Cap with 18-foot Pilot Chute
Maximum snatch load at booster	54,000 lb	85,000 lb
Time at snatch load	0.83 sec	0.64 sec
Apex position at vent cord break	118.3 ft	122.9 ft
Time at vent and break	0.925 sec	0.705 sec

The snatch load for the deployment from the nose cap with an 18-foot pilot chute is well below the inflation load, and this method is much more orderly and expedient. Opposite is a sample frame from a movie modeling the deployment in a crossflow, for the nose cap on tether concept, at the instant before the canopy starts out of the bag. Notice the large lateral deflection (line sail) experienced by the suspension lines.

DYNAFLATE SIMULATION OF DROGUE DEPLOYMENT
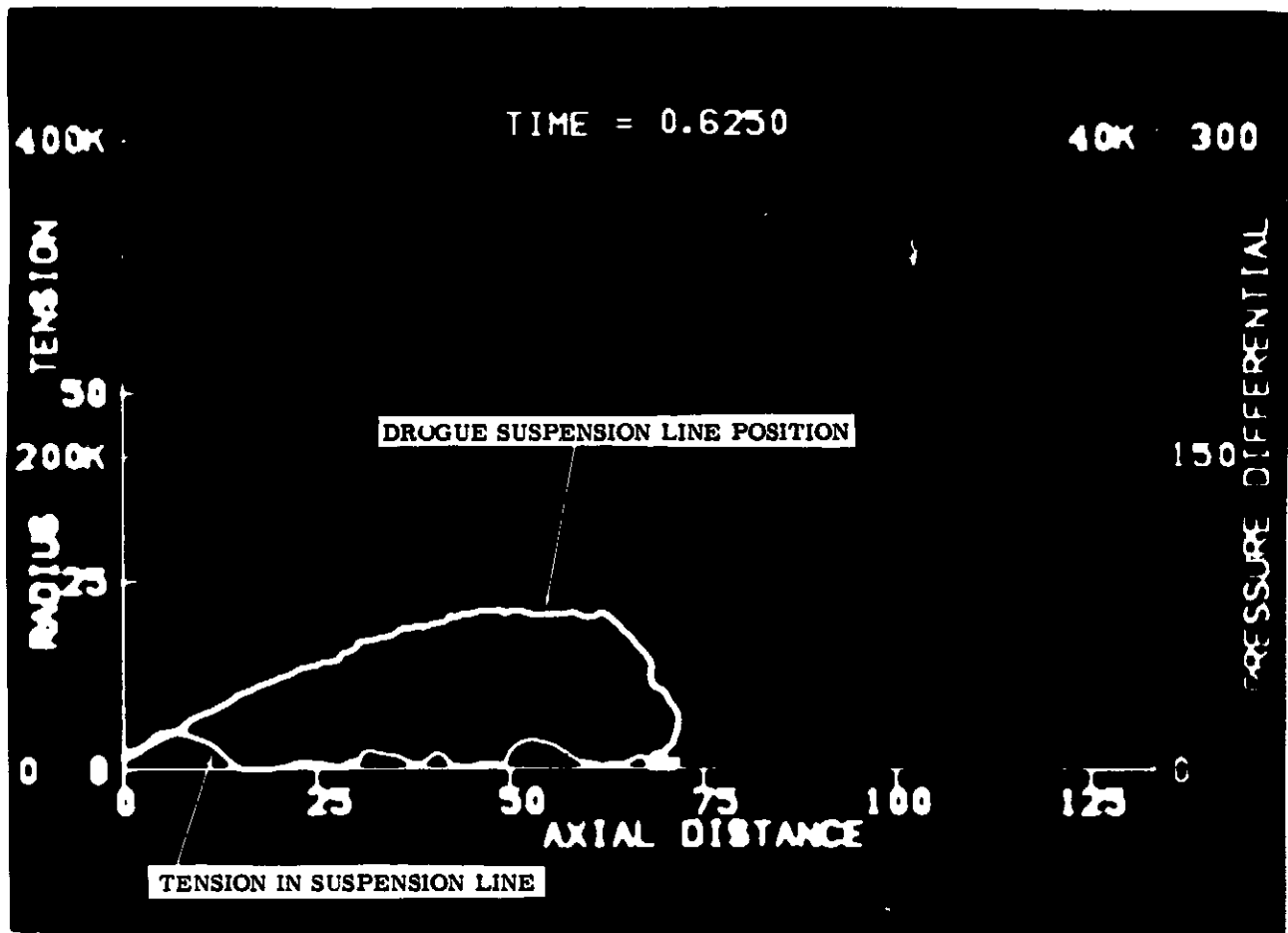
CRITERIA FOR EVALUATION OF PROPOSED DEPLOYMENT METHODS FOR THE SRB DROGUE PARACHUTE

As a part of the support being provided for analysis and preliminary design of the SRB recovery system, an evaluation of deployment methods proposed for the SRB drogue parachute has been conducted.

The proposed drogue for the SRB recovery system is a 54-foot diameter conical ribbon parachute weighing approximately 840 pounds. It is to be deployed near an altitude of 19,000 feet and at a dynamic pressure of approximately 200 lb/ft². At deployment time the SRB is in a near broadside attitude with potentially large dispersions in pitch, yaw, and roll angles and rates. The drogue is deployed from the nose of the SRB reefed to about 80 percent of its full open drag area. After the reefed drogue turns the SRB to a nozzle-first attitude, the drogue is disreefed to provide the proper deployment conditions for the main parachutes.

Several criteria were established by Sandia by which the candidate deployment methods were compared in this study. The criteria selected represent an attempt to combine acceptable parachute design practice with SRB development program philosophy.

The problem is to select one or more drogue deployment methods which satisfy the criteria. System cost was not considered specifically in the evaluation, but low system cost is indirectly reflected in all the requirements. Detailed cost trade-offs may be required to make a final selection if more than one acceptable deployment method exists.

Based on preliminary discussions, cost trade-offs and system interface requirements four drogue deployment methods were selected by NASA/MSFC for further evaluation. Deployments with (Methods 3 and 4) and without (Methods 1 and 2) a pilot chute were considered. An extensive series of drogue deployment wind tunnel tests described in References 1 and 2 below were conducted by NASA to investigate in detail the deployment methods illustrated in Figure 1. Observation of the films from the wind tunnel tests, computer simulation results, and experience gained in developing other large ribbon parachutes were combined to form the evaluations reported herein.

References

1. Vickers, J. A., "Wind Tunnel Test Plan - SRB Drogue Parachute System," Northrop Corporation, Ventura Division, NVR 74-16A, June 1974.

2. Utreja, L. R., "Wind Tunnel Test of the Space Shuttle Solid Rocket Booster Drogue Parachute System," Northrop Services, Inc., TR-230-1342, September 1974.

CRITERIA FOR EVALUATION OF PROPOSED DEPLOYMENT METHODS FOR SRB DROGUE PARACHUTE

1. STATE-OF-THE-ART DESIGN PRACTICE IS TO BE FOLLOWED.

2. THE SYSTEM SHOULD REQUIRE MINIMUM DEVELOPMENTAL FLIGHT TESTING.

3. THE DEPLOYMENT SHOULD BE CONTROLLED, PREDICTABLE, AND REPEATABLE WITHIN ACCEPTABLE LIMITS.

4. LITTLE OR NO DEPLOYMENT DAMAGE TO THE DROGUE SHOULD OCCUR, BECAUSE THE DROGUE IS TO BE REUSED APPROXIMATELY TEN TIMES.

DROGUE DEPLOYMENT METHOD NO. 1 (BASELINE)

In deployment Method No. 1 the following deployment sequence occurs:

1. The nose cap is ejected from the SRB with sufficient velocity (80 fps) to clear the drogue pack.

2. A tether connecting the nose cap and drogue pack extracts the drogue pack.

3. The drogue is deployed as the drogue pack separates from the SRB.

This method was selected by NASA as the baseline drogue deployment method primarily for cost reasons.

Initial objections to this deployment method were stated by Sandia because it did not follow state-of-the-art design practice (criterion 1). Heavy ribbon parachutes are nearly always deployed using a large extraction (pilot) parachute and high strength line and canopy ties. Criterion 2 would almost certainly be violated because extensive developmental testing of this rather unusual deployment method would be necessary. It was also suggested that the nose cap would provide insufficient drag to cause a rapid pack separation and to allow the use of heavy line ties. The result would be considerable line sail, a very disorderly deployment, and a significant and unpredictable amount of deployment damage. Based on past experience with similar parachutes, it was therefore suggested by Sandia that the baseline drogue deployment method (Method No. 1) was not acceptable because it satisfied none of the requirements for a successful system.

In order to investigate Method No. 1 in more detail, computer simulations and wind tunnel tests of the nose cap ejection and drogue bag extraction were conducted. Both the nose cap and drogue bag were simulated as six-degree-of-freedom bodies as described earlier in this section.

Wind tunnel test films for the Method No. 1 deployments showed essentially the same behavior as the computer simulations. The ejected nose cap quickly trims into the relative wind, the drogue pack is yanked from the SRB when the tether becomes taut, and much of the drogue deployment occurs when the pack is broadside or backwards.

During a significant portion of the deployment the relative deployment angle is 90 degrees or greater. At full scale velocities this misaligned deployment would almost certainly cause unacceptable damage to the drogue.

In summary, experience, analysis, and test all indicate that Method No. 1 (baseline) drogue deployment would be unacceptable for deployment of the SRB drogue.
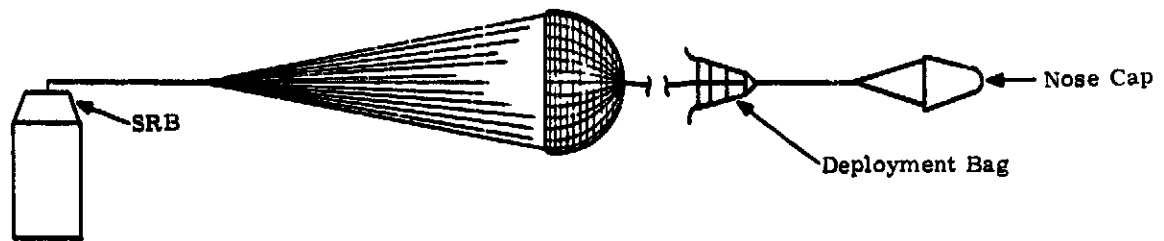
- NOT ACCEPTABLE FOR LARGE PARACHUTES

- UNCONTROLLED AND UNPREDICTABLE DEPLOYMENT WOULD RESULT IN COMPLETE FAILURE OR INCREASED DAMAGE ON DROGUE

DROGUE DEPLOYMENT METHOD NO. 2

In Method No. 2 the nose cap is ejected with the drogue packed inside. The drogue is thus deployed directly from the nose cap as the cap separates from the SRB.

This method would also be unacceptable for deployment of the SRB drogue. Since the nose cap quickly trims into the relative wind after it is ejected, a large relative angle between the pack and deploying drogue would also be present in this method. Also, as was illustrated in the wind tunnel tests, much more energy is required to separate the nose cap than would be the case in Method No. 1. Using the same separation energy as Method No. 1, the Method No. 2 wind tunnel nose cap and drogue pack fell to the wind tunnel floor and only deployed the drogue as the nose cap rolled along the floor.

Deployment Bag
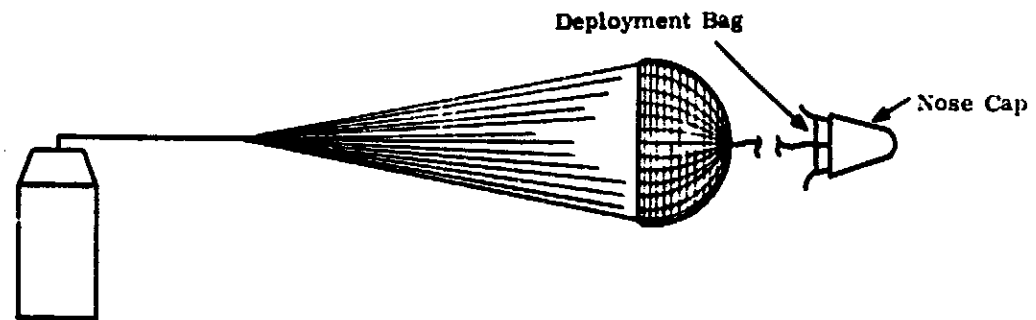
Nose Cap

* NOT ACCEPTABLE

* DID NOT WORK IN WIND TUNNEL

DEPLOYMENT METHOD NO. 3

Methods 3 and 4 use an extraction or pilot parachute to deploy the drogue. In Method No. 3 the deployment sequence is:

1. A pilot chute attached to the nose cap is deployed from the nose cap tip either using a mortar or the drag of a small section of the nose cap tip.

2. The nose cap with the drogue pack inside is released from the SRB or given a small separation velocity.

3. The pilot chute separates the nose cap and drogue pack from the SRB, deploying the drogue.

Results of a computer simulated Method 3 deployment were previously illustrated on page 2-15. The drogue pack angle-of-attack history was obtained using a computer simulation which assumed an 18-foot pilot chute. The pilot chute quickly aligned the drogue pack with the relative wind so that the deployment took place, as it should, with little relative angle between the pack and deploying parachute.

The wind tunnel test films of Method 3 show essentially the same behavior. In the wind tunnel test, a scaled 8-foot pilot chute was used. This chute was smaller than would be required for adequate deployment control and pack stability. However, Method 3 would appear to be an acceptable method of deploying the SRB drogue if a large enough pilot chute (15 to 20 feet) and a high strength line tie system were used.

Method 3 has a couple of possible advantages over Method 4. Little energy would be required to separate the nose cap, and the attached pilot chute should prevent any possibility of recontact of the nose cap with the SRB after parachute deployment. A possible problem with Method No. 3 would occur during the initial separation and rotation of the nose cap. Careful analysis would be required to insure that nylon components did not come in contact with the solid edges of the nose cap during this phase of deployment.

DROGUE DEPLOYMENT METHOD NO. 3
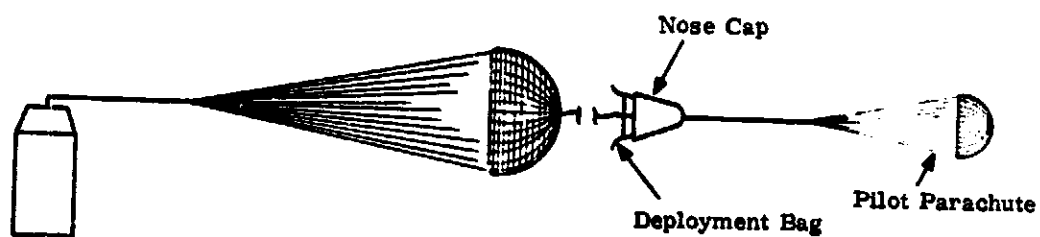
- COULD BE USED TO DEPLOY DROGUE

- NEED LARGER PILOT CHUTE AND STRONGER LINE TIES

- PILOT CHUTE COULD BE DEPLOYED BY EJECTING NOSE CAP TIP

- INITIAL SEPARATION NEEDS MORE STUDY

DEPLOYMENT METHOD NO. 4

In deployment Method No. 4 the following deployment sequence occurs:

1. The nose cap is ejected from the SRB with sufficient
    velocity to clear the drogue pack.

2. The separated nose cap deploys a pilot parachute.

3. The pilot parachute extracts the drogue pack from the SRB,
    deploying the drogue.

The wind tunnel test films showed that Method 4 provided reasonable deployment control, although like Method 3, the scaled 8-foot pilot chute was not large enough.

Method 4 would therefore be acceptable for deployment of the SRB drogue if a large enough pilot chute (15 to 20 foot diameter) and a high-strength line tie system are used. Method 4 has a couple of advantages over Method 3 which give it an overall advantage, and hence make it the preferred method. First, deploying the drogue from a deployment bag using a pilot chute is the most conventional system possible. Maximum use of past experience could be made, and minimum developmental testing would be required. Second, drogue deployment is made independent of the nose cap ejection. Dispersions in the SRB attitude and rates at drogue deployment would have only minor effects on the drogue deployment itself.

An additional wind tunnel series which would investigate pilot chute size, line tie strength, pilot chute riser length, nose cap tether length, and initial booster attitudes in greater detail would be extremely useful in designing the drogue deployment system.

Deployment Bag

Nose Cap

Pilot Parachute
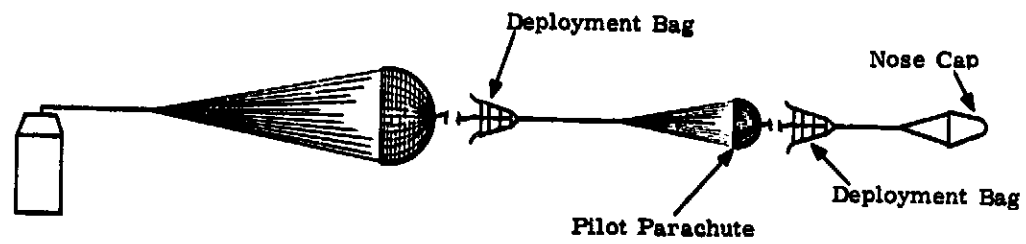
Deployment Bag

- PREFERRED DROGUE DEPLOYMENT METHOD

- NEED LARGER PILOT CHUTE AND STRONGER LINE TIES

- RUN MORE WIND TUNNEL TESTS TO OPTIMIZE SYSTEM

SECTION 3

PARACHUTE INFLATION ANALYSIS

BLANK PAGE

DESCRIPTION OF ANALYTICAL INFLATION MODEL

The analytical model used for the inflation analysis is described in detail in Ref. 3-1. The approach used differs from methods developed by others in that it utilizes momentum equations rather than a conservation-of-mass equation to describe the motion of the parachute canopy.

The major assumptions made for the inflation analysis are listed below:

1. The parachute canopy is modeled as two lumped masses, each with two degrees of freedom.

2. Aerodynamic forces are approximated by the sum of quasi-steady and fluid inertia forces.

3. Quasi-steady forces include a drag force proportional to parachute cross-sectional area and a radial force proportional to the inflated canopy area forward of the maximum radius point.

4. Fluid inertia forces proportional to axial and radial acceleration are included.

5. The portion of the canopy from the skirt to the maximum radius point is approximated by a conical frustum, while the canopy aft of the maximum radius is approximated by an oblate spheroid with constant eccentricity.

6. Elastic forces are obtained from static load-strain data for the materials used in the parachute.

7. The forebody and parachute are assumed to follow the same ballistic path.

Trajectory coordinates used in the inflation model are defined. Six degrees of freedom are required: three flight path coordinates (forebody, parachute skirt and parachute maximum radius point), two radial coordinates (parachute skirt and parachute maximum radius point), and the flight path angle.

Trajectory coordinates for inflation model.
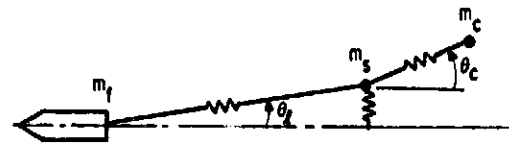
Schematic of elastic components
in inflation model.
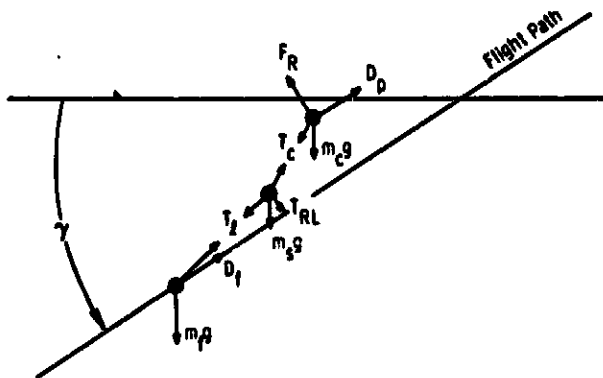
System forces during inflation.
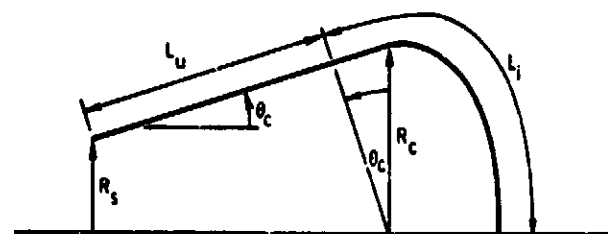
Canopy geometry for inflation model.

AERODYNAMIC DATA IN INFLATION MODEL

Aerodynamic forces on the parachute in the axial (drag) and radial directions are expressed as a function of geometric porosity in the inflation model. The data were extracted from wind tunnel and flight tests of parachutes. Because the aerodynamic data are expressed in this way, parachute porosity can be specified independently in any inflation analysis.

$$C_D = 1.75 - 3.15\lambda_{gc}$$

o Reference 12
x 76-Ft Diameter Parachute
+ 23-Ft Diameter Parachute

Drag Coefficient

Geometric Porosity Including Strain

Effect of porosity on full-open drag coefficient based on projected area.

$$\frac{C_R}{C_D} = 0.625 - 0.316\lambda_{gc}$$

x o Reference 12
⊗ 1st Stage 76-Ft Diameter Parachute
x 2nd Stage 76-Ft Diameter Parachute
+ 23-Ft Diameter Parachute

Radial Force Coefficient/Drag Coefficient

Geometric Porosity Including Strain
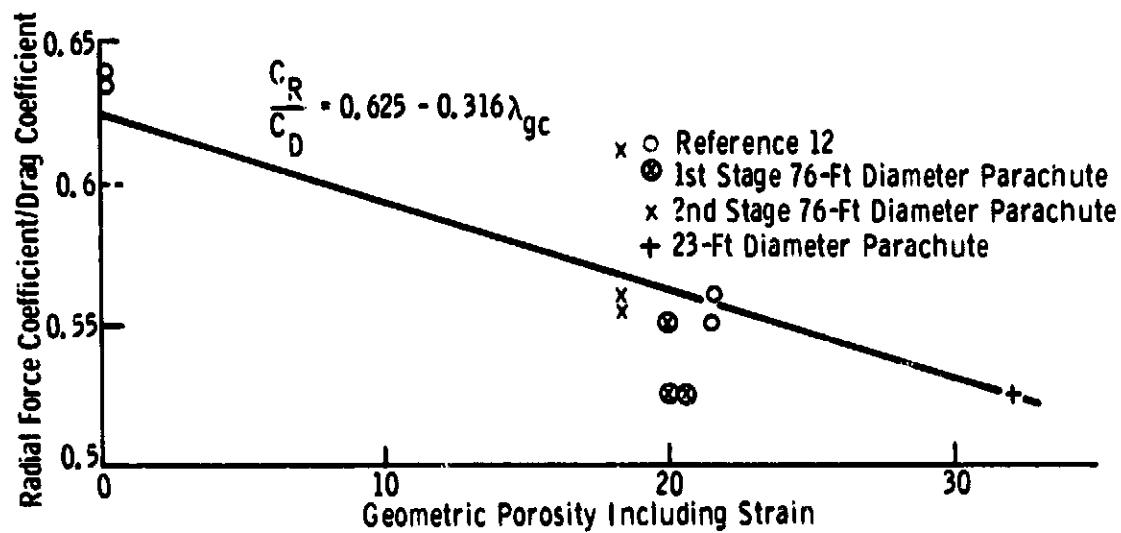
Effect of porosity on radial force coefficient.

COMPARISON OF PREDICTED INFLATIONS WITH TEST DATA

Predicted force and geometry during inflation were compared with flight test data in Ref. 3-1.

Solutions to the equations of motion were compared with available shape and load data for the 23-ft ribbon parachute (Ref. 3-2) and the 76-ft ribbon parachute (Ref. 3-3) developed by Sandia. Shape and parachute dimensional data were obtained from computer-generated plots of digitized flight film frames.

Force measurements were taken from forebody accelerometer data.

A sample comparison of actual and predicted data for a test of the 23-ft parachute is shown opposite. The comparisons of predicted loads and shapes with the experimental data are good, considering the simplicity of the inflation model. Data from a test of the 76-ft parachute also are compared with predicted geometry and load data. Again, the comparisons are quite good.

Based on these comparisons, it is concluded that the inflation model should accurately predict the forces and shapes for the SRB drogue and main parachutes during inflation.

COMPARISON OF PREDICTED INFLATIONS WITH TEST DATA
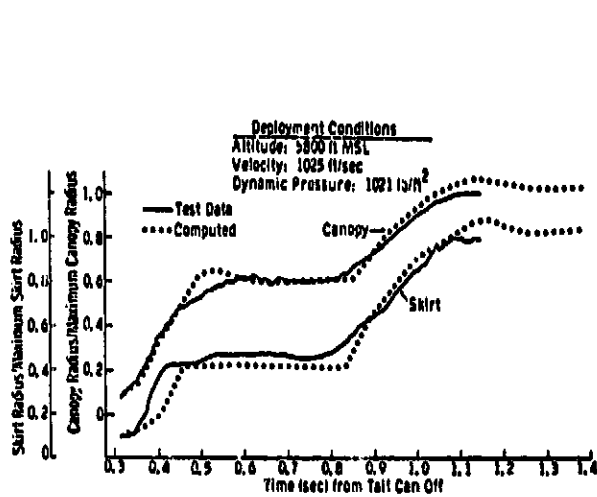
Nondimensional radii vs. time,
23-ft parachute, test 352.
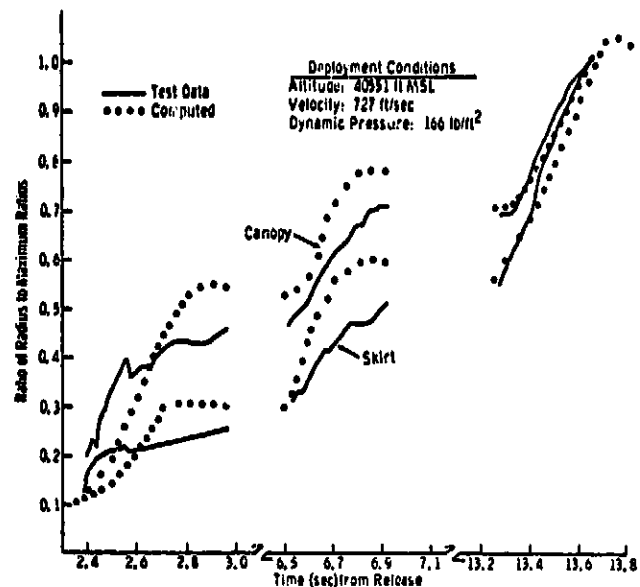
Inflated shape for 76-ft parachute,
test B-5.
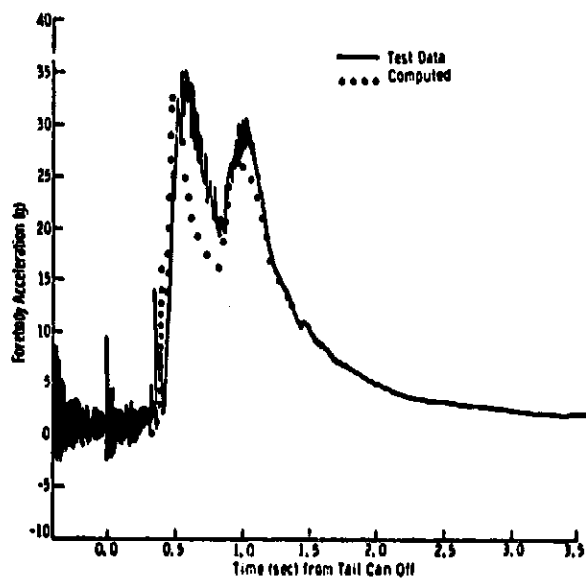
Forebody acceleration data,
23-ft parachute, test 352.
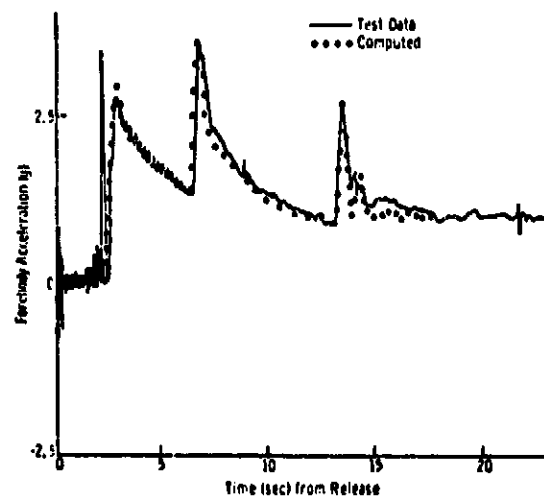
Forebody acceleration data,
76-ft parachute, test B-5.

NOMINAL CONDITIONS FOR DROGUE INFLATION STUDY

The configuration used for the SRB drogue parachute inflation study is defined in Ref. 3-4. The drogue is a 20° conical ribbon parachute with a nominal diameter of 54 feet and a suspension line length of 96 feet. An average geometric porosity of 16 percent is specified in Ref. 3-4, although other porosities were assumed in the study when required. The basic inflation model was modified for the drogue inflation analysis to include a three-degree-of-freedom planar motion SRB rather than a point mass forebody. The parachute was assumed to be aligned at all times with the relative velocity at the attach point on the SRB. Initial conditions at the start of drogue inflation were obtained from NASA SRB trajectory studies. Drogue inflation was assumed to start at an altitude of 10,000 feet and a dynamic pressure of 200 psf with the SRB in a vertical trajectory and a broadside attitude. A nominal reefing time of 12 sec was specified by NASA and was used for all inflations. In most cases the reefing line length was adjusted to provide equal maximum loads on both the reefed and full open drogue.

NOMINAL CONDITIONS FOR DROGUE INFLATION STUDY

- DROGUE CONFIGURATION — ASD-ASTN-1816 (REF. 3-4)

- INITIAL ALTITUDE = 19,000 FT

- INITIAL DYNAMIC PRESSURE = 200 LB/FT^2

- INITIAL TRAJECTORY ANGLE = -90° (VERTICAL)

- INITIAL SRB PITCH ANGLE = 0° (HORIZONTAL)

- REEFED TIME DELAY = 12 SEC

SRB DROGUE INFLATION — POROSITY - 16 PERCENT, NO SRB WAKE INTERFERENCE

In the initial analysis of the SRB drogue inflation the configuration specified in Ref. 3-4 was used directly into the inflation model with no reduction in parachute drag due to SRB wake effects. An SRB weight of 164,000 pounds was used. Although the SRB turn-around and pitch angle decay was quite similar to that being used by NASA, the inflation loads of approximately 280,000 pounds were significantly larger than the 226,000 pounds design load in use. The difference was attributed to two causes. First, the configuration being analyzed produced significantly more steady drag that was being assumed for performance and loads calculations. Second, the fairly low porosity of the (16 percent) produced a significant dynamic or "opening shock" effect.

SRB DROGUE INFLATION — POROSITY = 16 PERCENT, NO SRB WAKE INTERFERENCE
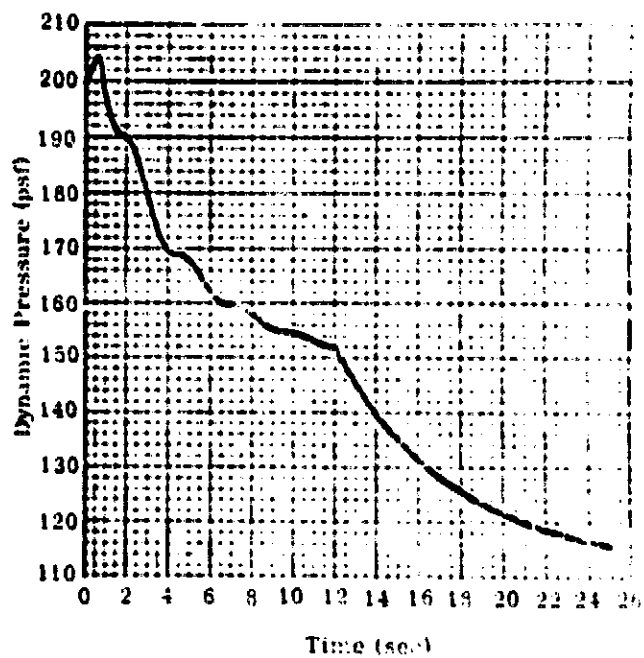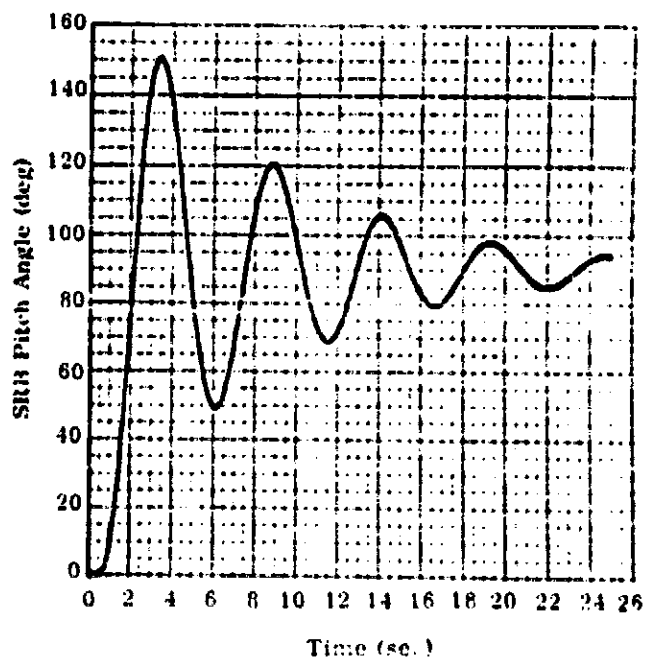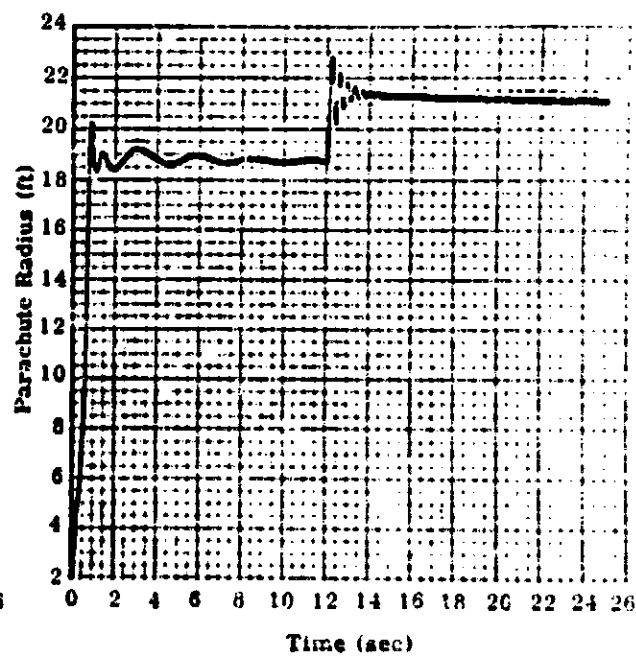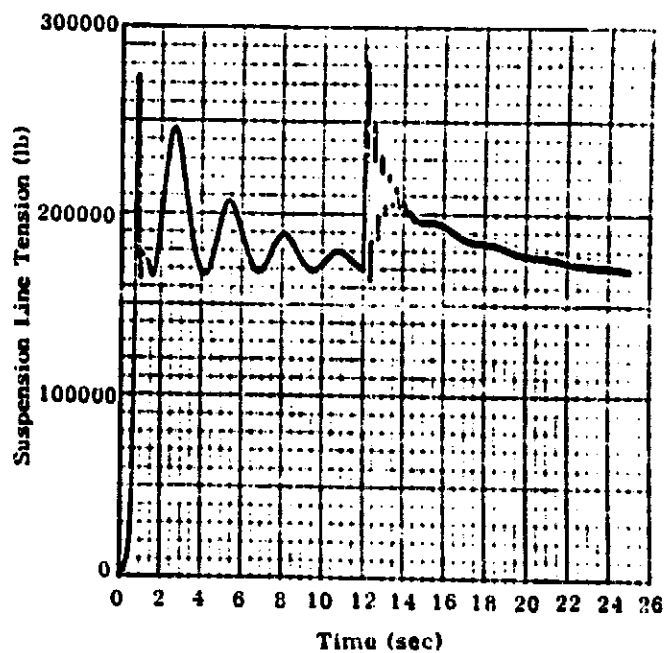
PARACHUTE OPENING SHOCK FACTOR

The variation of parachute drag coefficient with porosity and suspension line length is discussed elsewhere in this report (p. 1-15). An addition important effect which influences parachute inflation loads is the dynamic or "opening shock" effect. The ratio of maximum force to steady drag force was measured by Sandia in a series of wind tunnel tests of 3-foot diameter ribbon parachutes of different porosities (Ref. 3-5). For low porosity ribbon chutes (porosity of about 20 percent or less), the opening shock factor becomes large and cannot be ignored in calculating inflation loads.

OPENING SHOCK FACTOR VS.
GEOMETRIC POROSITY LTV LOW SPEED WIND TUNNEL TESTS

Figure axis labels: vertical axis $\dfrac{F_{max}}{F_{steady}}$, horizontal axis Geometric Porosity.
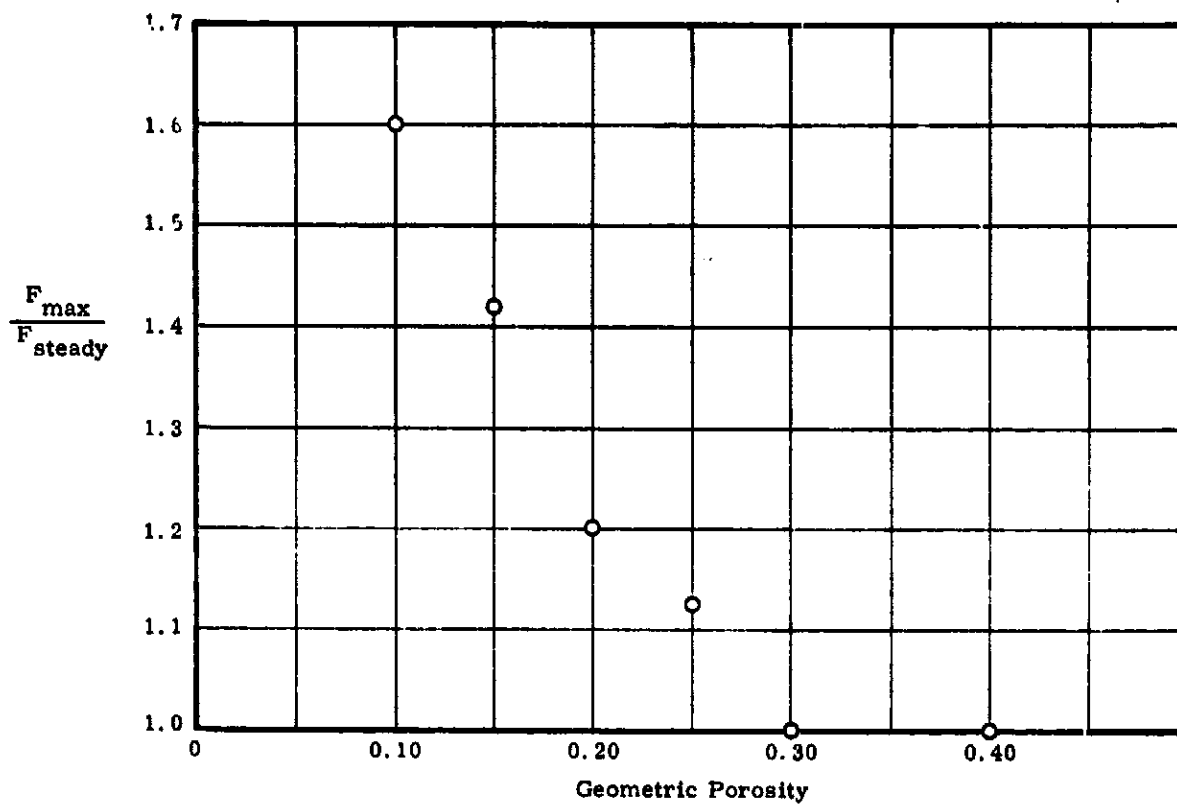
SRB DROGUE INFLATION — POROSITY = 21 PERCENT, NO SRB WAKE INTERFERENCE

Inflation loads for an SRB drogue with geometric porosity of 21 percent were generated. This porosity provided approximately the desired full open drag area for the 54-foot diameter drogue. Again, no SRB wake interference was assumed. An SRB weight of 164,000 pounds was used. Inflation loads of about 240,000 pounds were much closer to those used by NASA to design the drogue. SRB turn-around dynamic motion was essentially unchanged.

SRB DROGUE INFLATION — POROSITY = 21 PERCENT, NO SRB WAKE INTERFERENCE
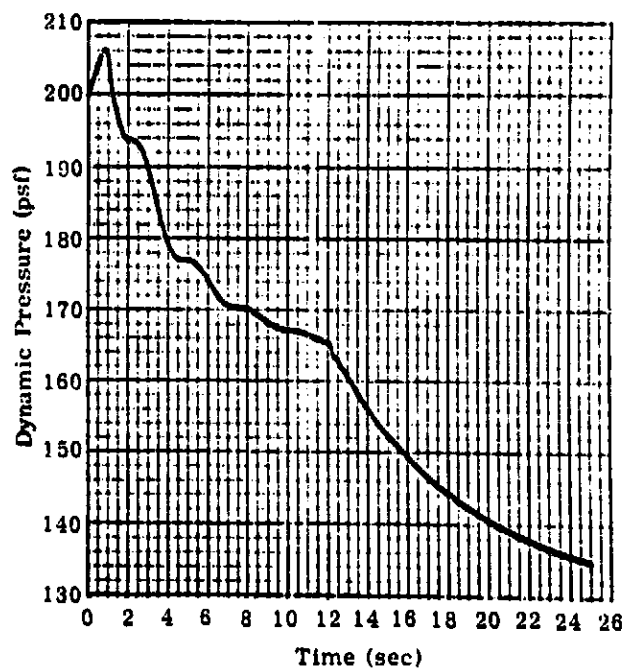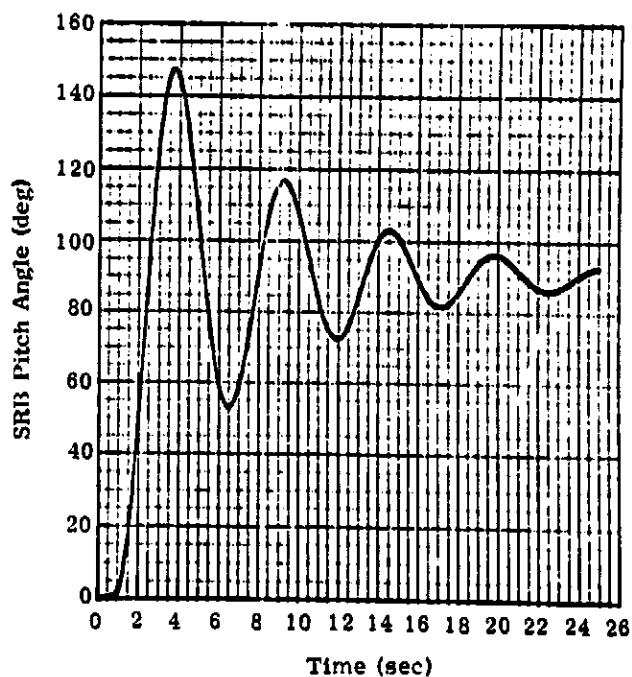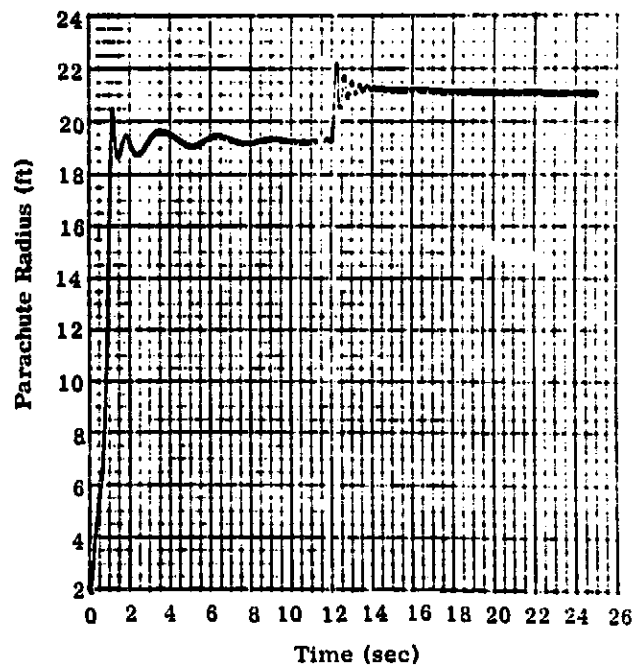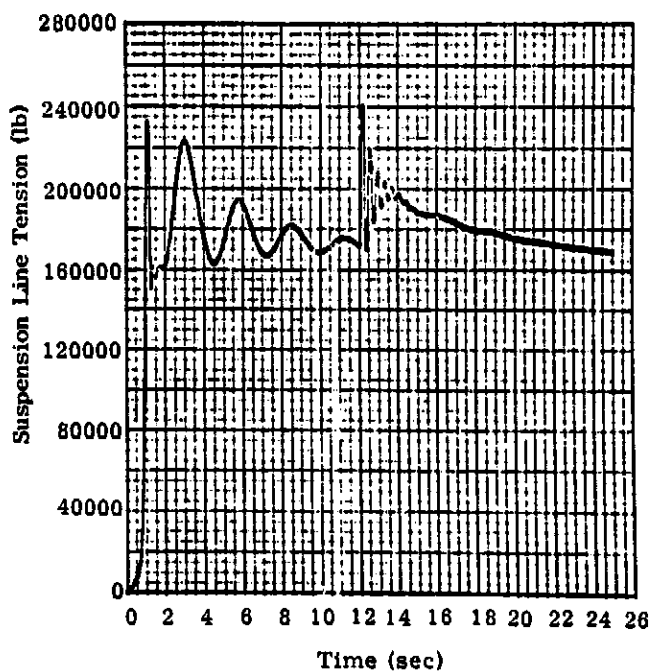
SRB DROGUE INFLATION — POROSITY = 16 PERCENT, NO SRB WAKE INTERFERENCE, INCREASED SRB WEIGHT

SRB weight during the drogue phase was increased to 171,400 pounds. The weight increase caused a slight increase in maximum inflation load for the 16 percent porosity drogue. The larger SRB weight was used in all succeeding inflation studies.
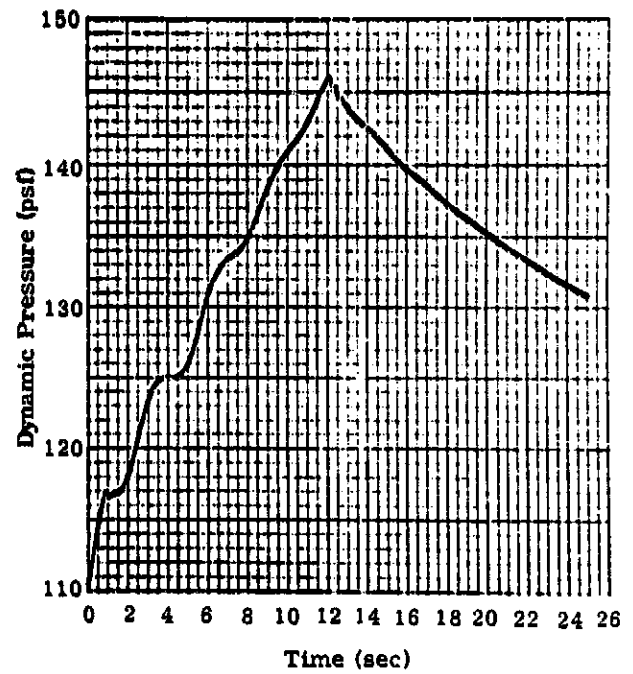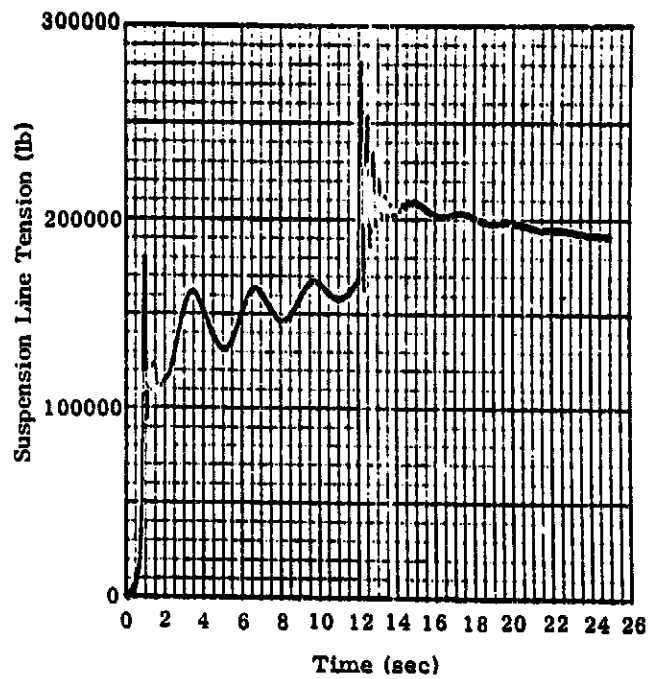
SRB DROGUE INFLATION — POROSITY = 16 PERCENT, NO SRB WAKE INTERFERENCE,
INCREASED SRB WEIGHT
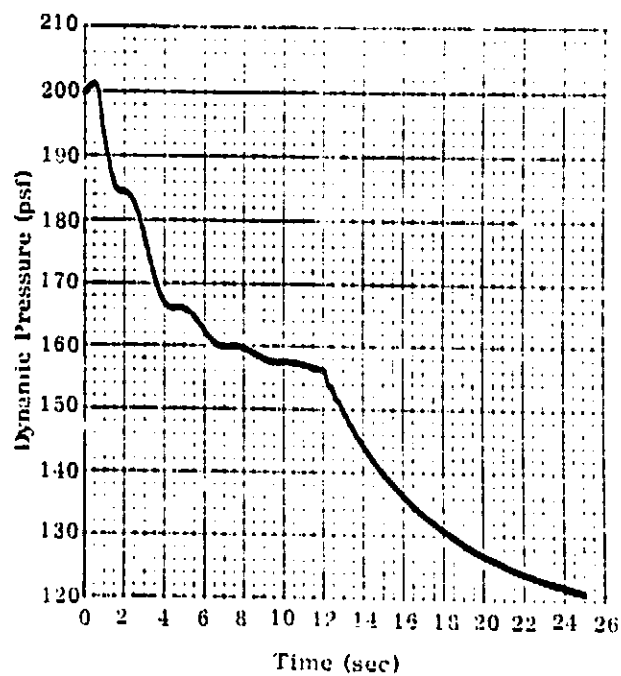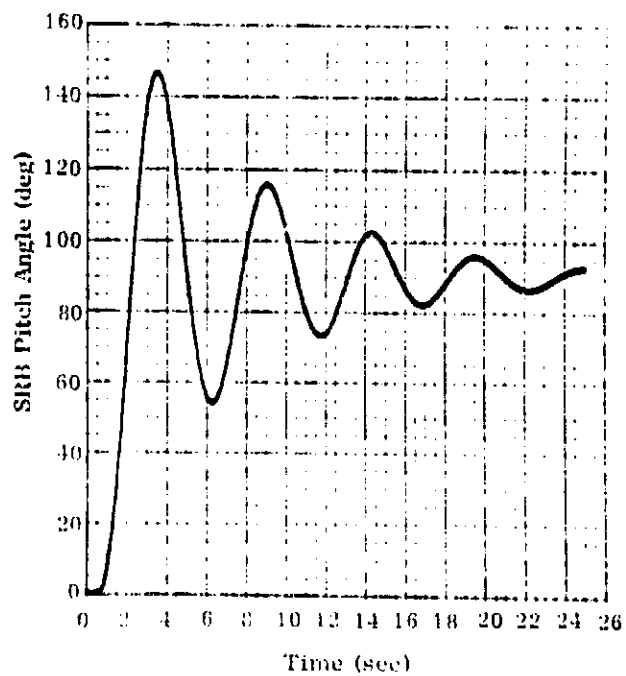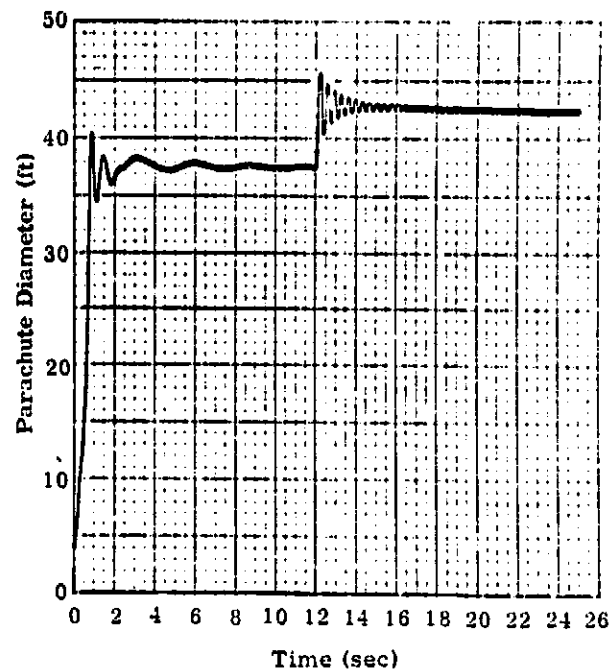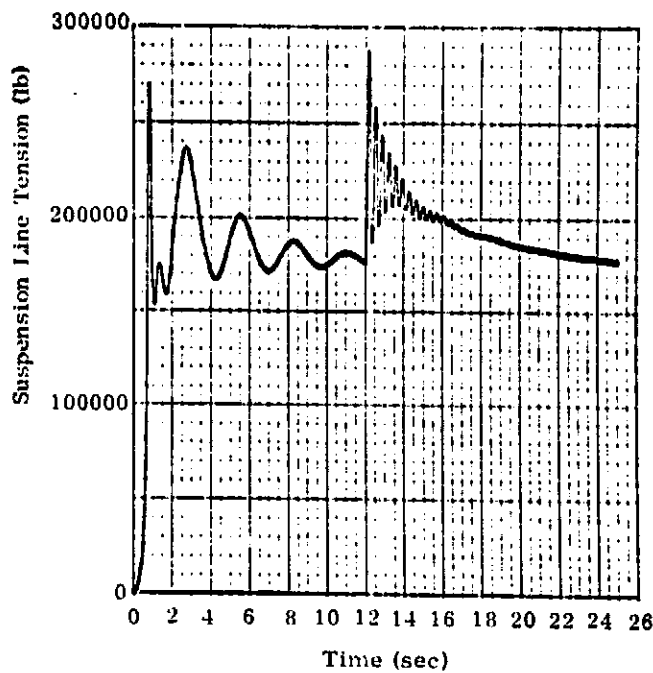
SRB DROGUE INFLATION — HIGH ALTITUDE DEPLOYMENT

In support of a study of other methods of initiating recovery, drogue inflation was simulated for deployment at an off-nominal trajectory condition. An initial altitude of 40,000 feet and a dynamic pressure of 110 lb/ft^2 were used. The 16 percent porosity drogue with no SRB wake interference and an SRB weight of 171,400 pounds were assumed. Reefing ratio and reefing time were kept at nominal values. Maximum second stage inflation load of 280,000 pounds is seen to be about the same as that for a nominal deployment.
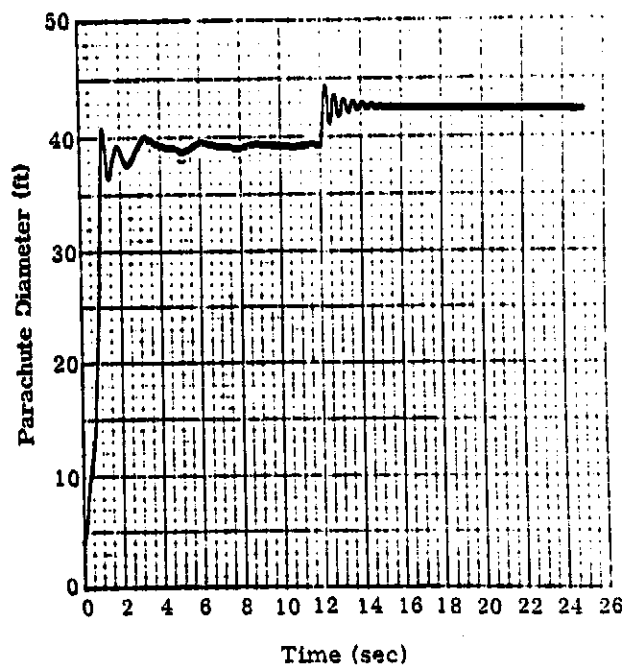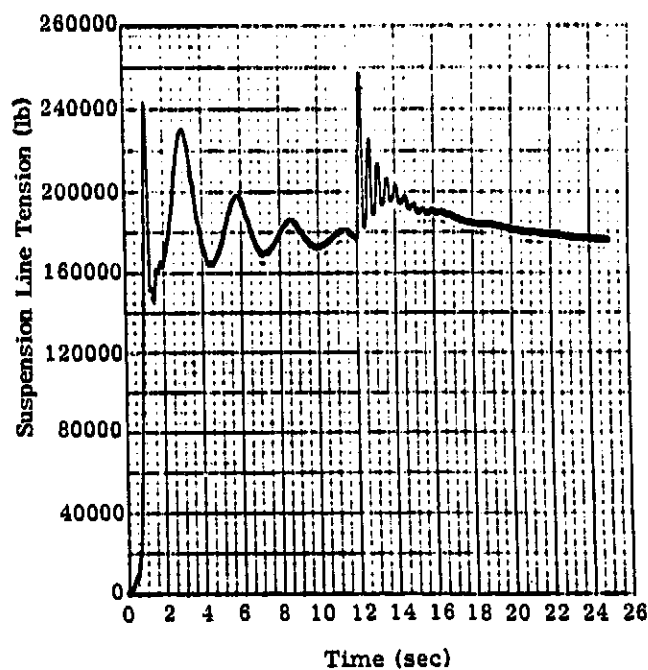
SRB DROGUE INFLATION — POROSITY = 16 PERCENT, 12 PERCENT DRAG REDUCTION DUE TO SRB WAKE

Wind tunnel tests conducted by NASA (Ref. 3-6) on scale models of the SRB drogue in the presence of the SRB revealed a significant reduction in parachute drag due to the SRB wake. Maximum inflation loads for the 16 percent porosity drogue with the drag coefficient reduced by 12 percent (typical of the wind tunnel wake interference results) are seen to be reduced from 280,000 pounds to about 250,000 pounds. Reefing line length was increased from the no-interference case to balance first and second stage loads. SRB weight remained at 171,400 pounds.
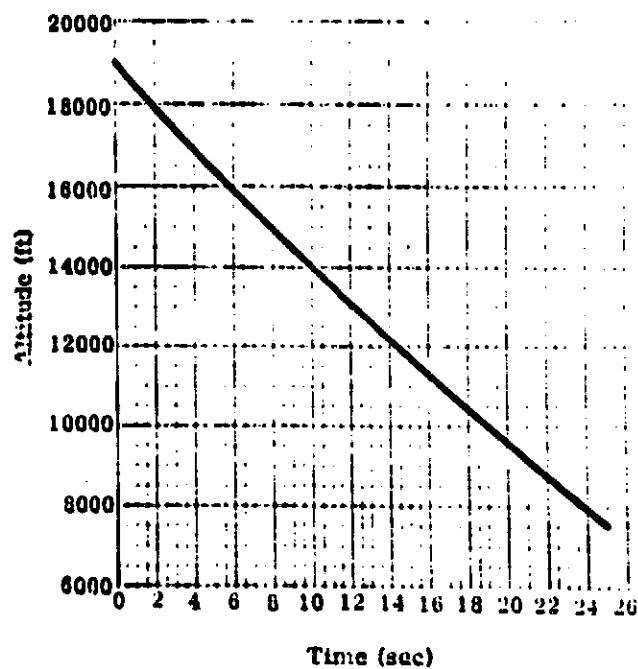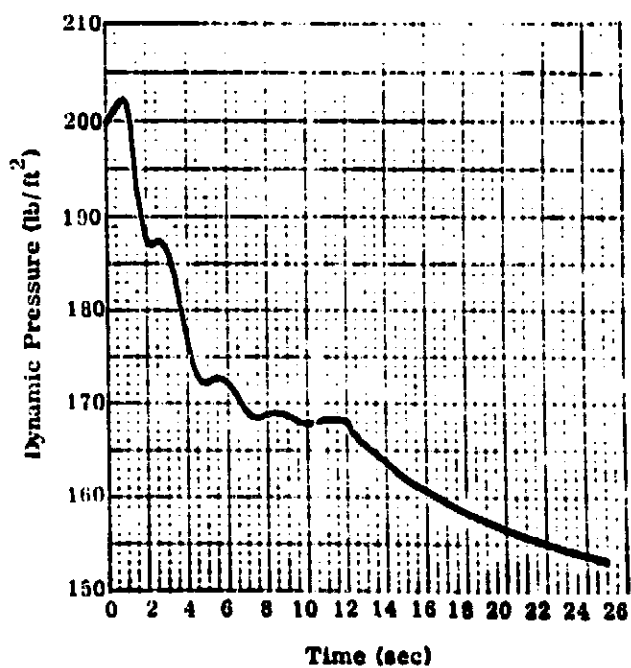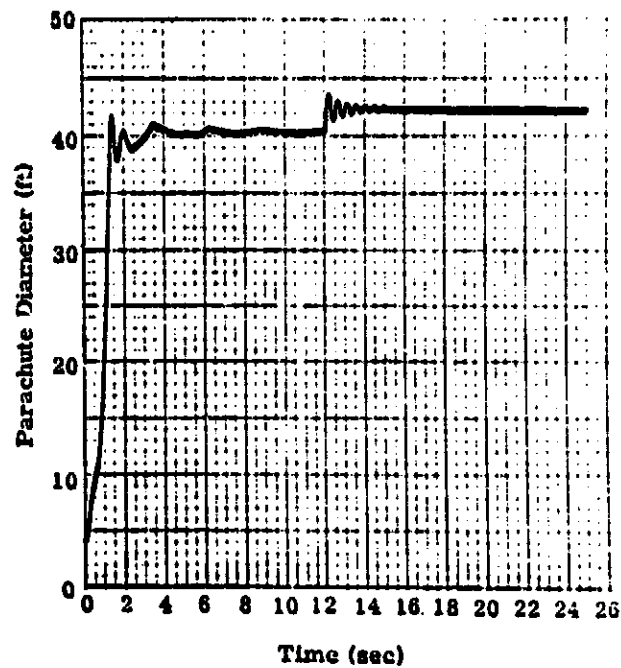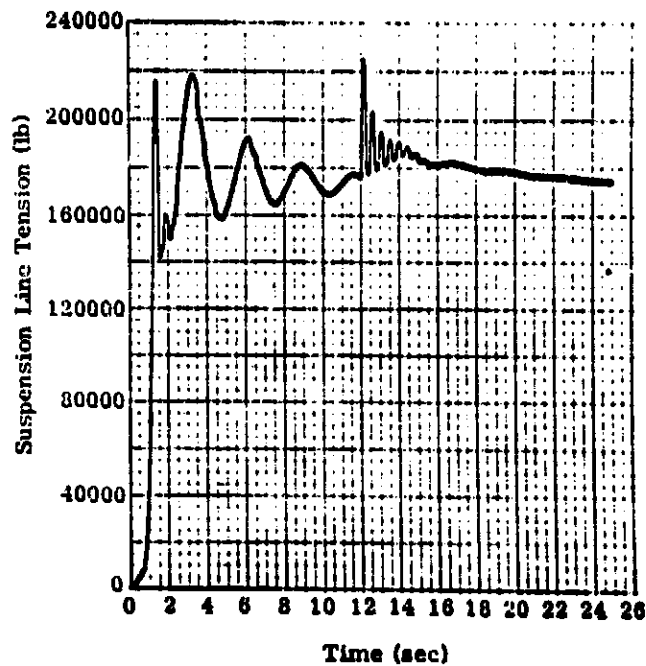
SRB DROGUE INFLATION — POROSITY = 20 PERCENT, 12 PERCENT DRAG REDUCTION DUE TO SRB WAKE

Wind tunnel data from Ref. 3-6 indicated that for a 54 foot chute with 96 foot suspension lines, a 20 percent porosity chute would be required to provide the desired drag in the SRB wake. After increasing the reefing line length to balance maximum loads on both stages, the maximum inflation loads for the 20 percent porosity drogue in the SRB wake were approximately 220,000 pounds.

SRB DROGUE INFLATION — POROSITY = 20 PERCENT, 12 PERCENT DRAG REDUCTION
DUE TO SRB WAKE

SRB DROGUE INFLATION — POROSITY = 20 PERCENT, 12 PERCENT DRAG REDUCTION DUE TO SRB WAKE, 10°/SEC PITCH DOWN RATE

The effect of an initial pitch down rate on SRB drogue inflation loads was investigated. An initial pitch rate of 10°/sec and an initial 20° nose up pitch attitude were used. The maximum inflation load on the first stage occurs when the SRB is approximately horizontal for this set of initial conditions. The pitch rate effect is seen to increase maximum inflation loads from 220,000 to 226,000 pounds.

SRB DROGUE INFLATION — POROSITY = 20 PERCENT, 12 PERCENT DRAG REDUCTION
DUE TO SRB WAKE, 10°/SEC PITCH DOWN RATE
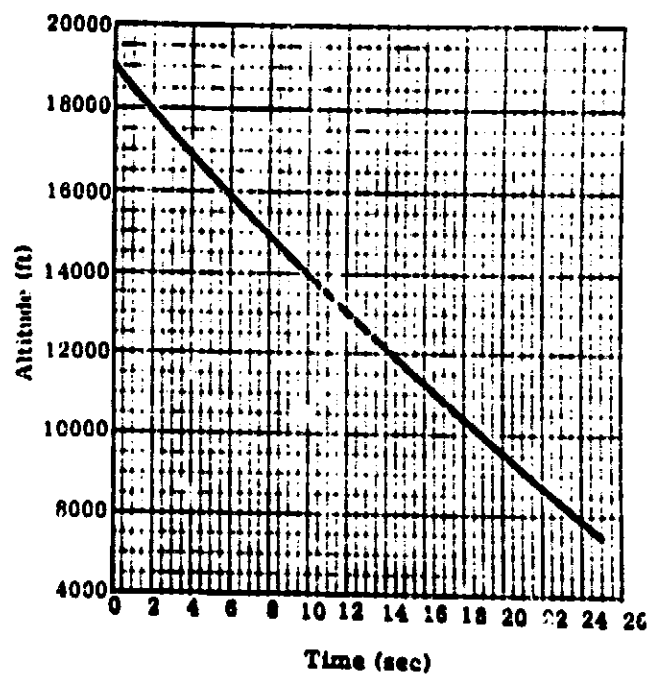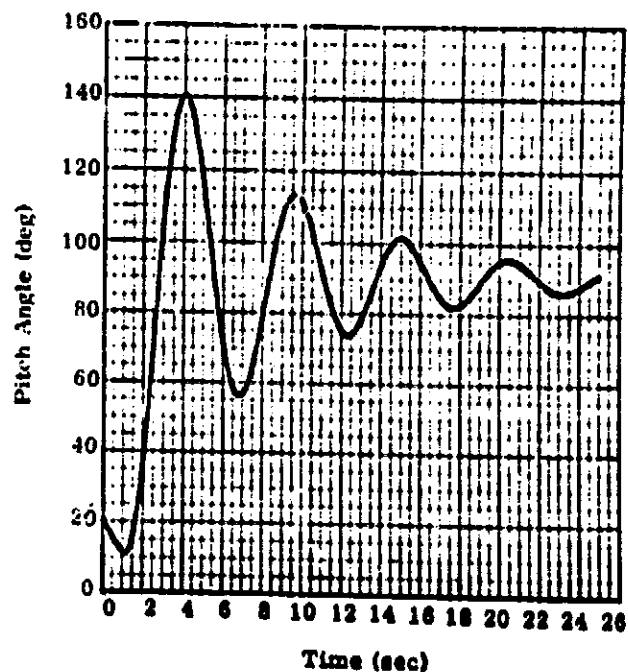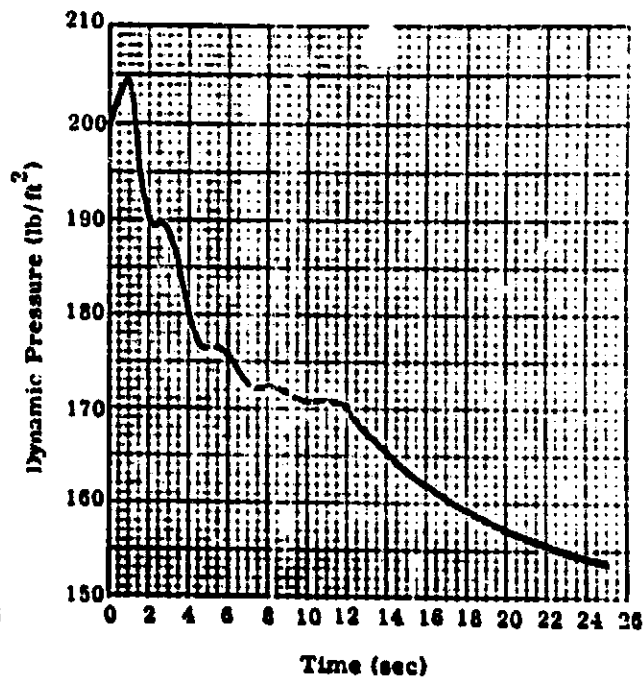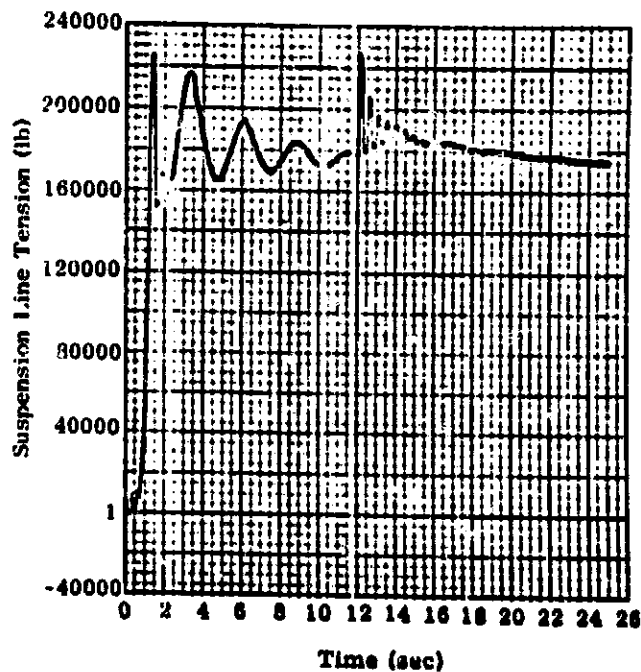
SRB DROGUE INFLATION — REDUCTION IN FIRST STAGE LOAD

Due to SRB structural design considerations, it has been suggested that the first stage drogue inflation load be less than the second stage load. First stage load subjects the SRB to large bending moments while the second stage load causes only minor bending moments. A series of inflation simulations with smaller reefing line lengths were run. A 20 percent porosity drogue with a 12 percent SRB wake effect was used. An initial pitch down rate of 10°/sec and an initial pitch attitude of 20° nose up were assumed, an SRB weight of 171,400 pounds was used. From a balanced load condition of 226,000 pounds, a deliberate load unbalance of 140,000 pounds minimum and 310,000 pounds maximum was obtained.

SRB DROGUE INFLATION — REEFING LINE LOADS

A unique feature of the analytical inflation model is that reefing line loads are calculated along with other elastic loads in suspension lines and radials. The maximum reefing line load is merely the hoop tension resulting from the radial force required to restrain the mass concentrated at the parachute skirt. Load/strain data for the reefing line material must be input into the inflation program. The model provides a very conservative calculation of maximum reefing line tension because the large mass concentrated at the parachute skirt causes a dynamic amplification which is considerably greater than the actual condition where mass is distributed along the suspension lines and radials. An attempt was made to filter out this dynamic effect by adding critical viscous damping to the reefing line force and plotting only the elastic part of the force. The critically damped case is considered more realistic for design purposes. The nominal initial conditions were assumed for both cases except that an initial pitch attitude of 20° nose up and pitch rate of 10° per second nose down were used. Calculated reefing line tension for the undamped case was 4100 pounds and for the critically damped case was 3450 pounds.

SRB DROGUE INFLATION — REEFING LINE LOADS

No Damping

Critical Damping
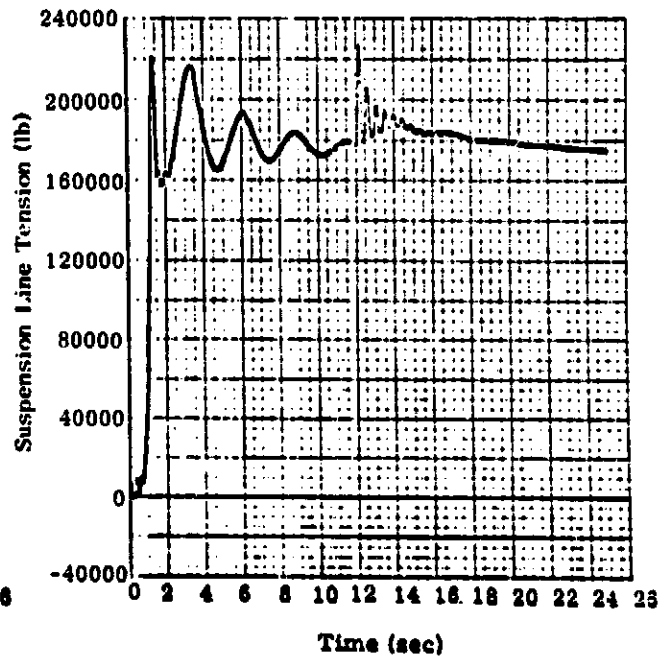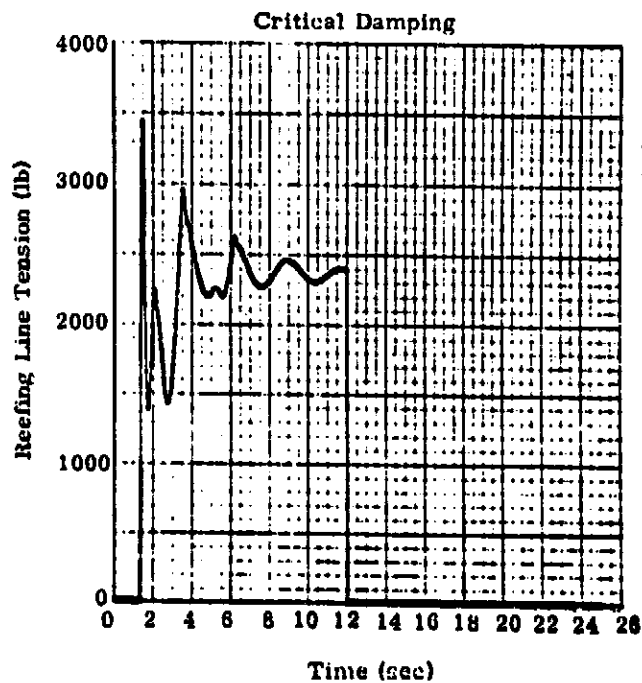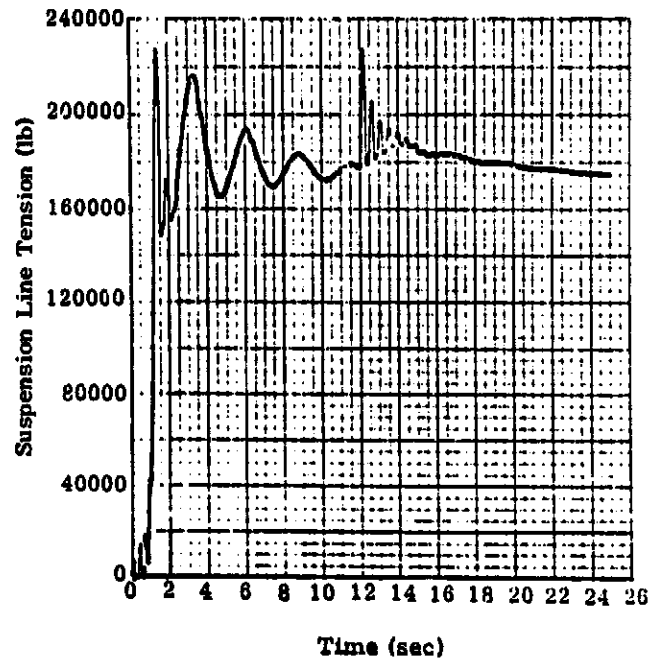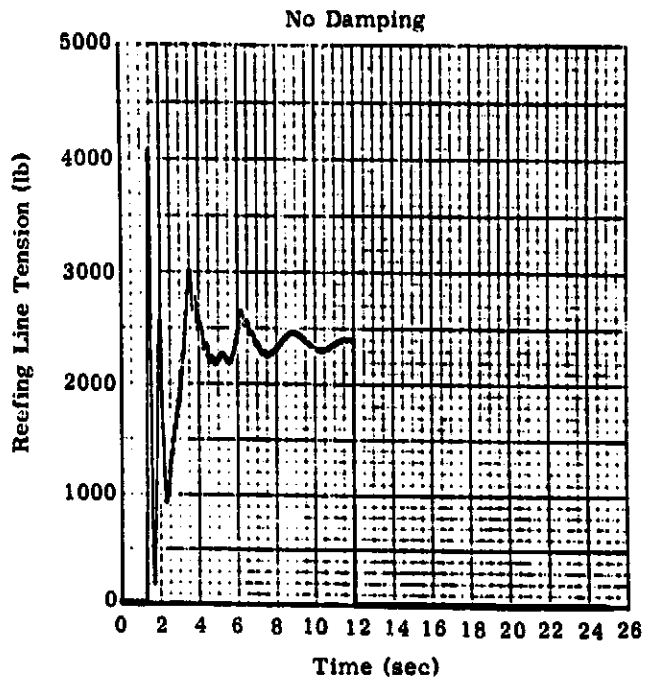
NOMINAL CONDITIONS FOR MAINS INFLATION STUDY

The configuration used for the SRB main parachute inflation study is defined in Ref. 3-4. Three 104-foot diameter 20° conical ribbon parachutes with a suspension line length of 104 feet form the main cluster. An average porosity of 16 percent is specified for the main cluster. The basic inflation model was used for the main chute inflation analysis except in a few cases where multiple independent parachutes were coupled to the point mass forebody. Initial conditions at the start of main inflation were obtained from NASA SRB trajectory studies. Main parachute inflation was assumed to start at an altitude of 8860 feet and a dynamic pressure of 147 psf with the SRB in a vertical trajectory and a tail-first attitude. Nominal reefing time delays of 13 seconds and 8 seconds were specified by NASA.

NOMINAL CONDITIONS FOR MAIN INFLATION STUDY

- MAIN CONFIGURATION · ASD · ASTN · 1816 (REF. 4)

- INITIAL ALTITUDE = 8860 FEET

- INITIAL DYNAMIC PRESSURE = 147 LB/FT^2

- INITIAL TRAJECTORY ANGLE = -90° (VERTICAL)

- INITIAL SRB PITCH ANGLE = 90° (VERTICAL)

- FIRST REEFED TIME DELAY = 13 SEC.

- SECOND REEFED TIME DELAY = 8 SEC.

SRB MAINS INFLATION — NOMINAL CASE

In the initial analysis of the SRB main chute inflation the configuration specified in Ref. 3-4 was input directly into the inflation model. All three parachutes were assumed to inflate in a perfectly synchronous manner. The maximum inflation load of 130,000 pounds per parachute predicted on the first two stages was similar to NASA predictions. The predicted final stage inflation load of 125,000 pounds was significantly higher. A rapid final stage inflation resulting in a larger than expected final stage load was also observed in tests of the Sandia developed 76 foot chute (Ref. 3-3). Since the inflation model correctly predicts this behavior the predicted final stage inflation loads for the SRB main chutes are considered realistic. SRB weight during main parachute operation was assumed to be 159,000 pounds.
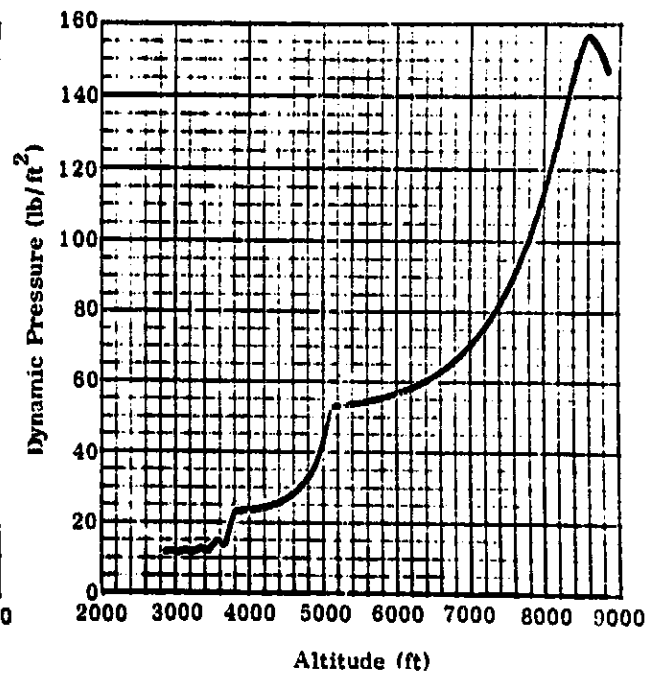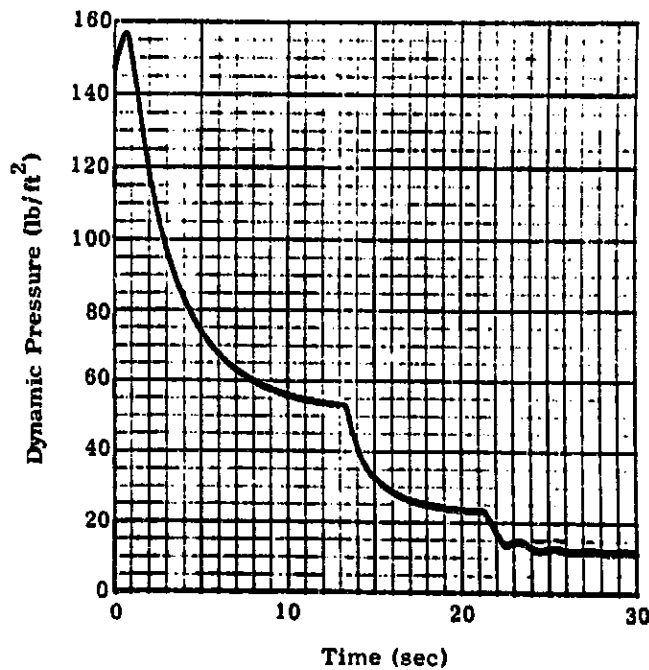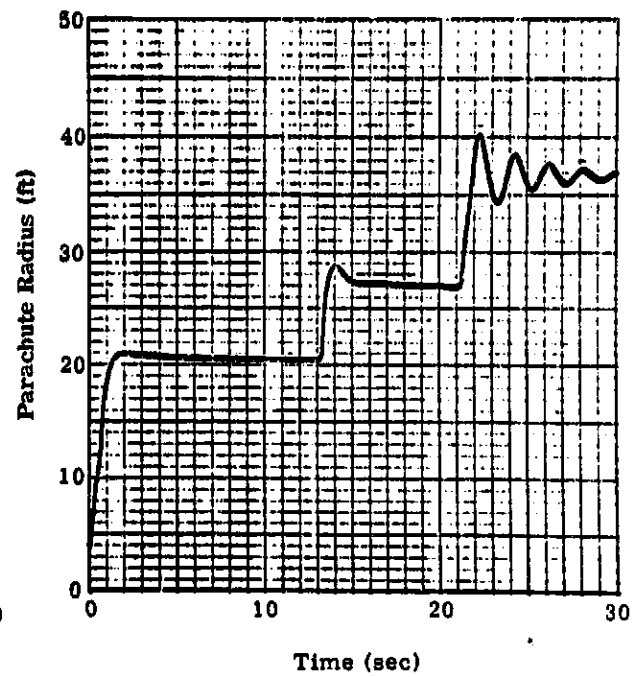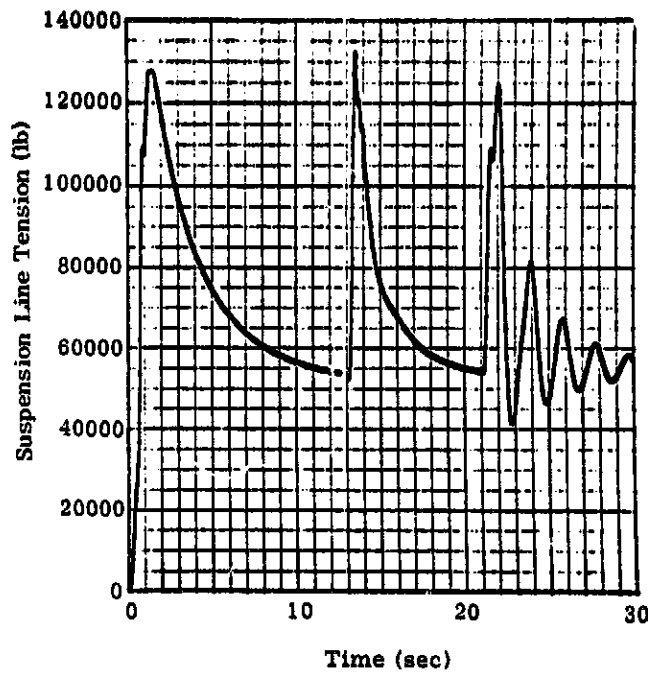
SRB MAINS INFLATION — NONSYNCHRONOUS DISREEFING

One of the major problems encountered in the use of reefed parachutes in clusters is the problem of nonsynchronous disreefing of individual parachutes. This can occur if initiation of all cutter time delays is not perfectly simultaneous or if tolerances in cutter time delays cause significantly different disreef times. Nonsynchronous disreefing can cause unequal loadings in parachutes, and since it is not known ahead of time which parachute will inflate first and carry the largest load, all parachutes must be designed to the higher load experienced by the "lead" parachute. In order to estimate the magnitude of this problem the inflations of all three parachutes in the cluster were modeled independently using the inflation program. Time delay tolerances for pyrotechnic reefing cutters are in the range of 5 percent to 10 percent of delay time. Inflation loads were calculated for an early disreef of 5 percent and 10 percent of the largest (13 second) time delay on one parachute. Maximum inflation loads on the lead chute were approximately 145,000 pounds. The difference between this value and the nominal value was within the unequal loading tolerance being used by NASA.

SRB MAINS INFLATION — NONSYNCHRONOUS DISREEFING

5% Early Disreef
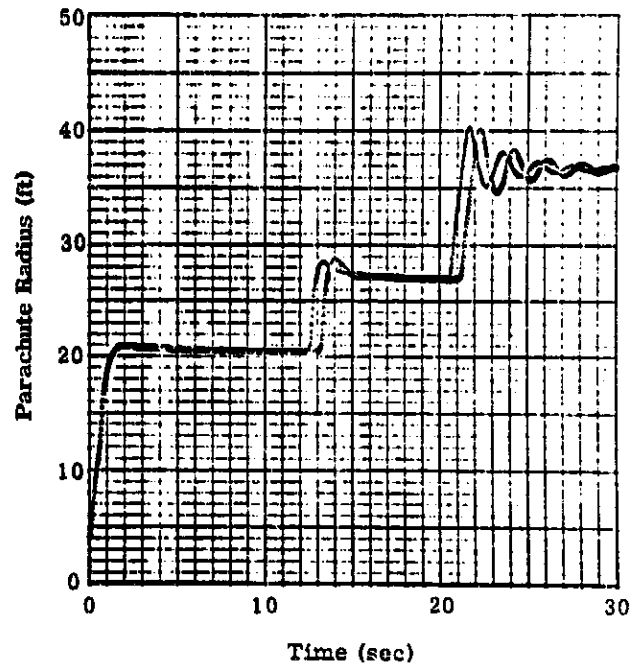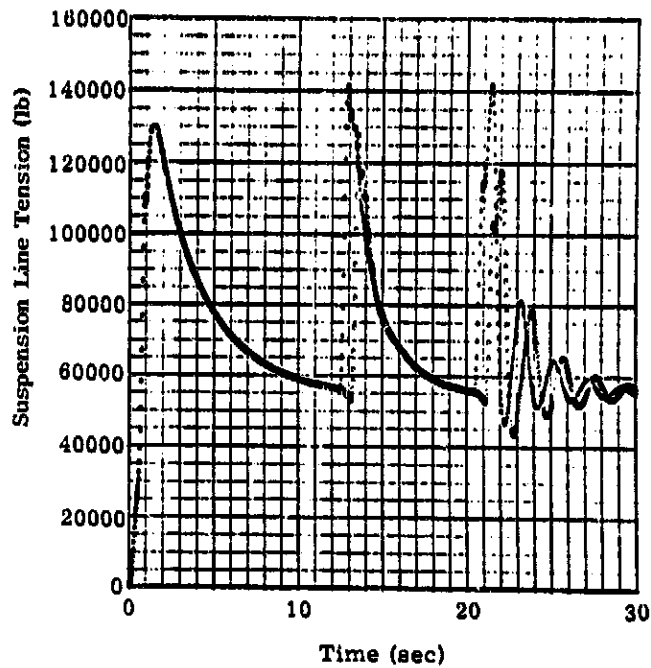
10% Early Disreef
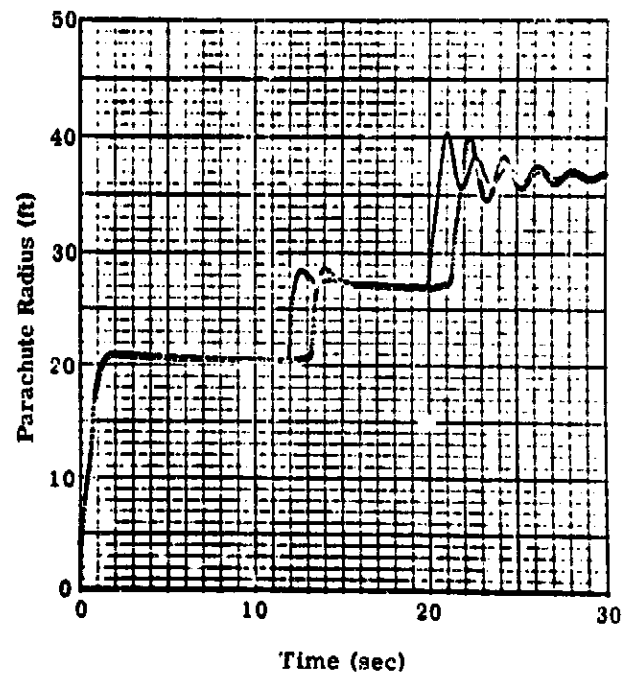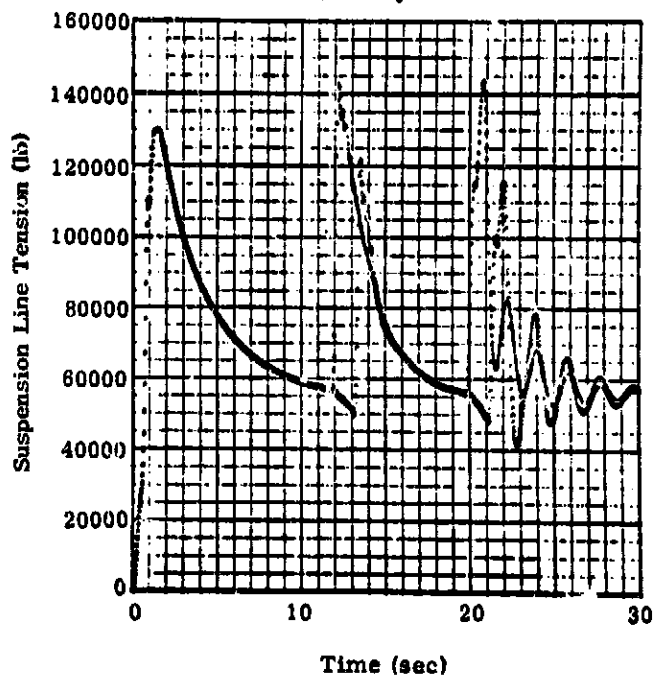
SRB MAINS INFLATION — NOMINAL CASE, INCREASED SRB WEIGHT

The nominal (perfectly sychronous) inflation of the SRB main cluster was simulated for an increase in SRB weight to 167,000 pounds during main chute generation. Maximum inflation loads were increased slightly to about 135,000 pounds, and the final stage load was increased to a level nearly equal to the first two stages.
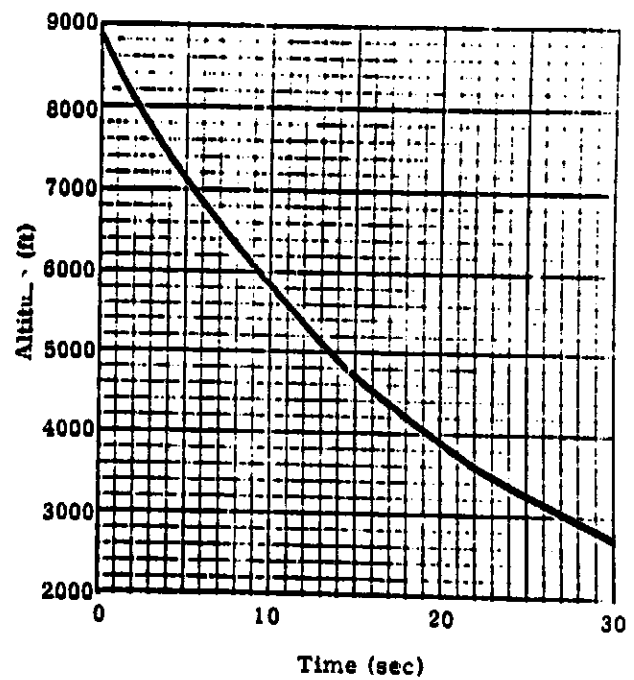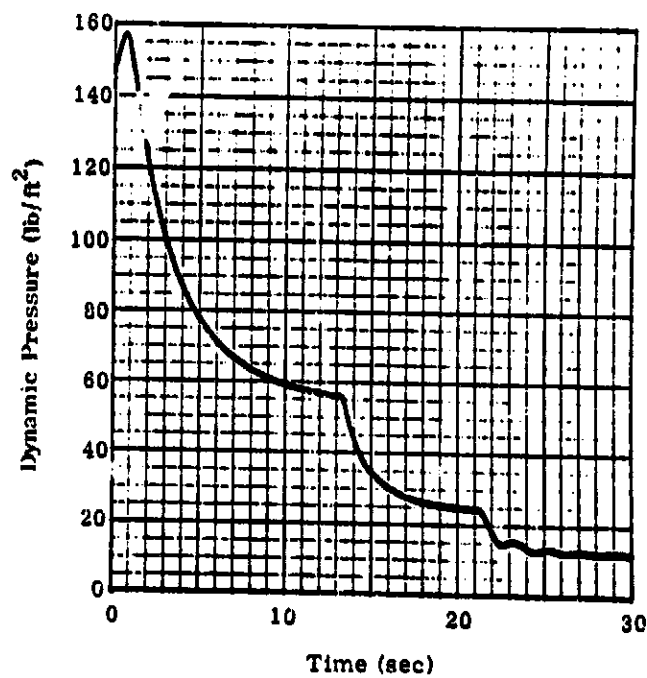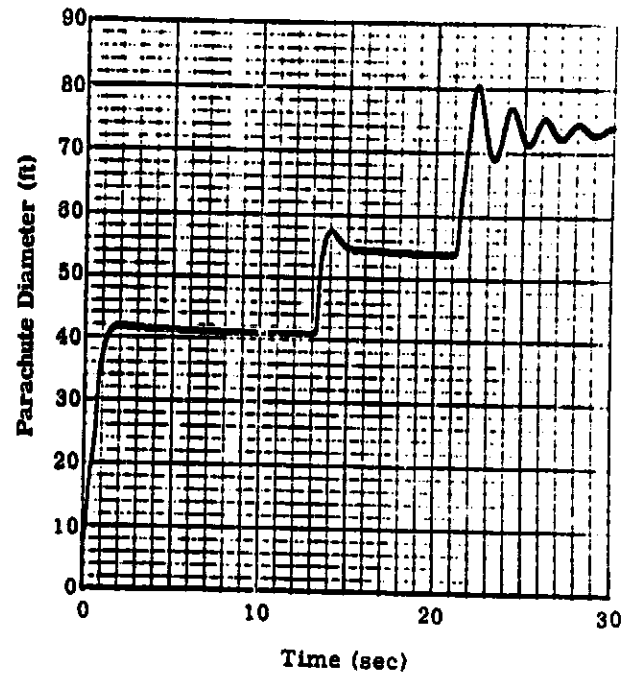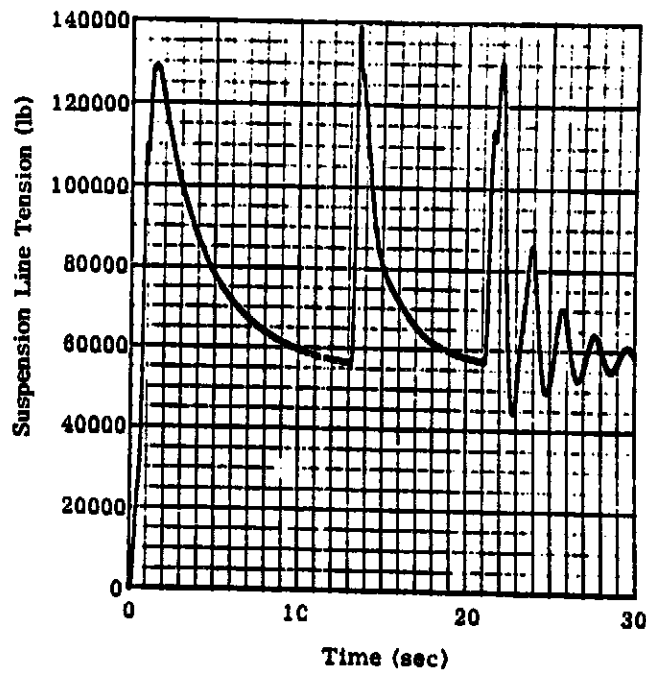
SRB MAINS INFLATION — HIGH ALTITUDE DEPLOYMENT

The effect of deployment of the SRB main chutes at a much higher altitude (35,000 feet) was investigated. Initial dynamic pressure, reefing line lengths, and reefed time delays remained unchanged. Maximum inflation loads on the second and third stages were increased to about 160,000 pounds. The increased loads at higher altitudes is expected since at higher altitudes longer delay times are required to provide a given amount of deceleration.

SRB MAINS INFLATION — HIGH ALTITUDE DEPLOYMENT
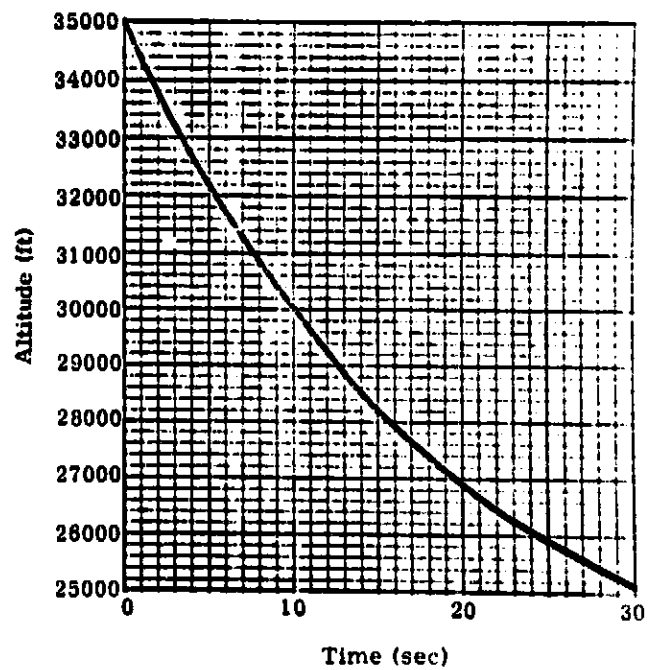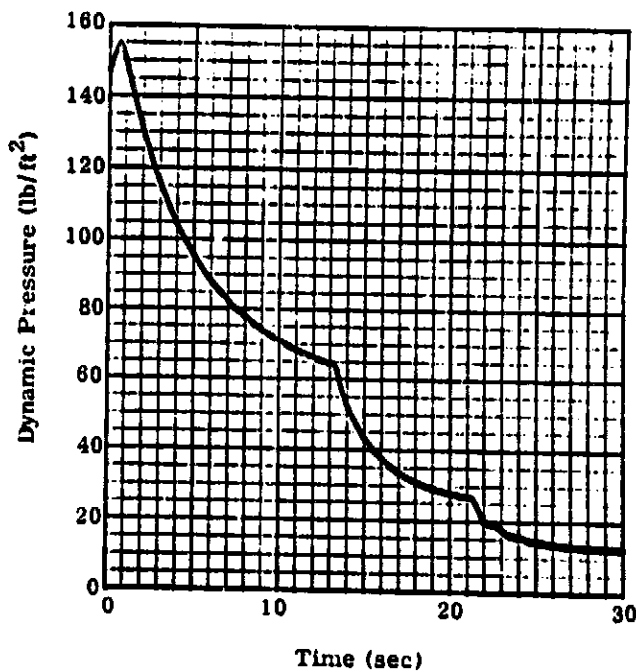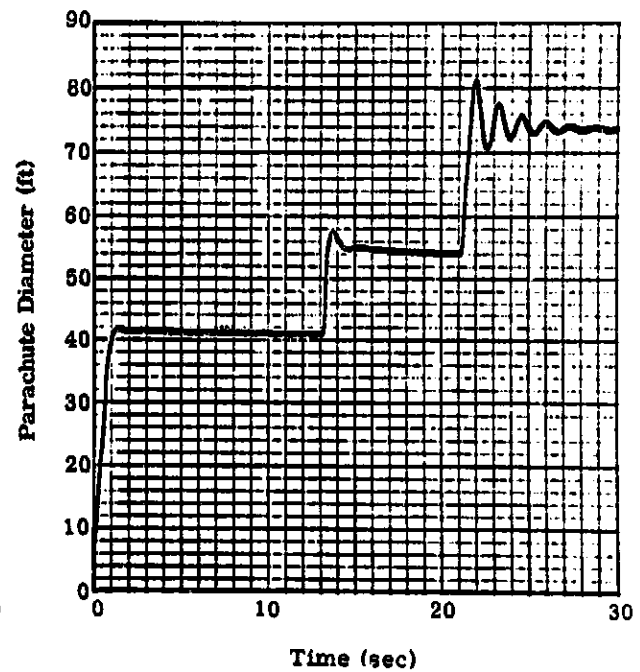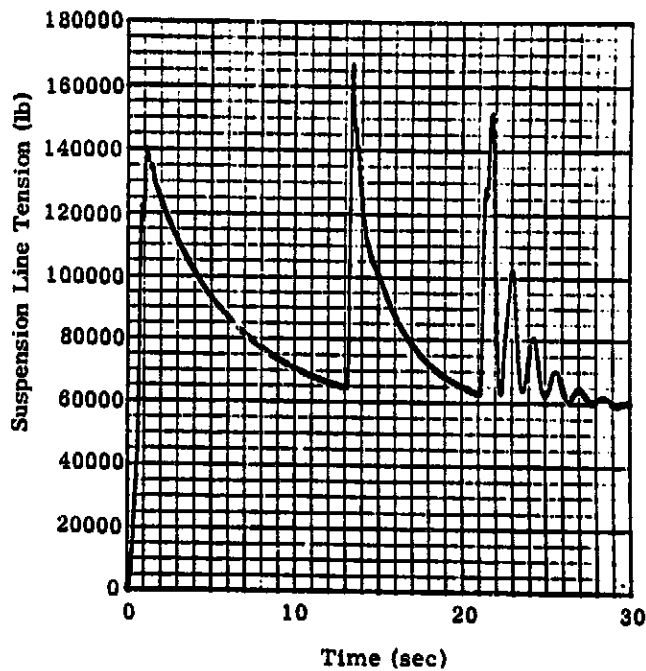
SRB MAINS INFLATION — REEFING LINE LOADS

Maximum reefing line loads were also calculated for the SRB main chutes using the inflation program. Maximum loads for no damping (6000 pounds) and critical damping (5000 pounds) in the reefing line were calculated. Of these, the lower value for the critically damped case is considered more realistic for design purposes. An SRB weight during main chute operation of 167,000 pounds was used.

SRB MAINS INFLATION — REEFING LINE LOADS
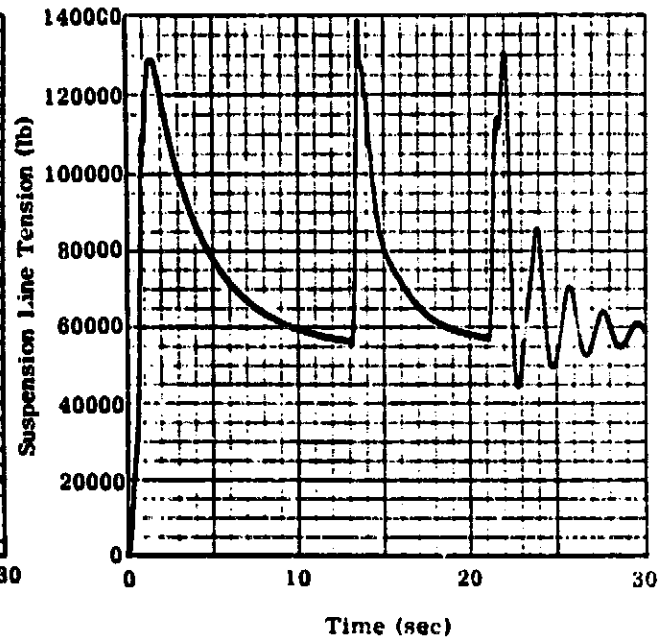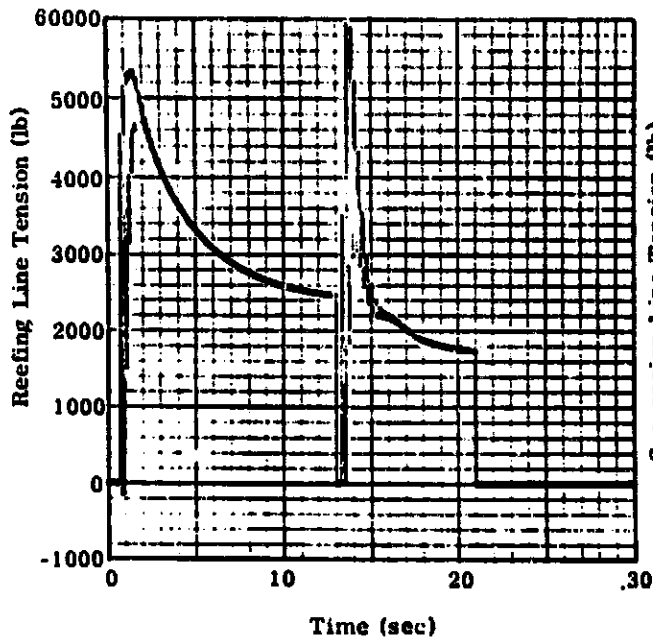
No Damping

Critical Damping
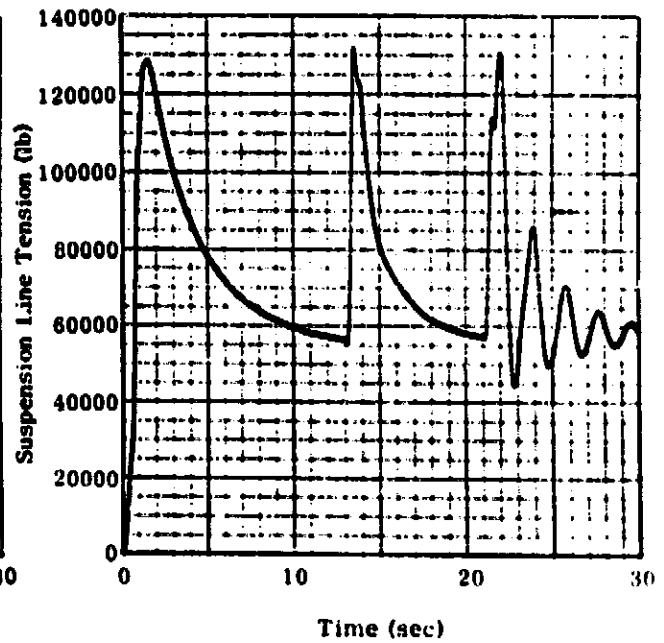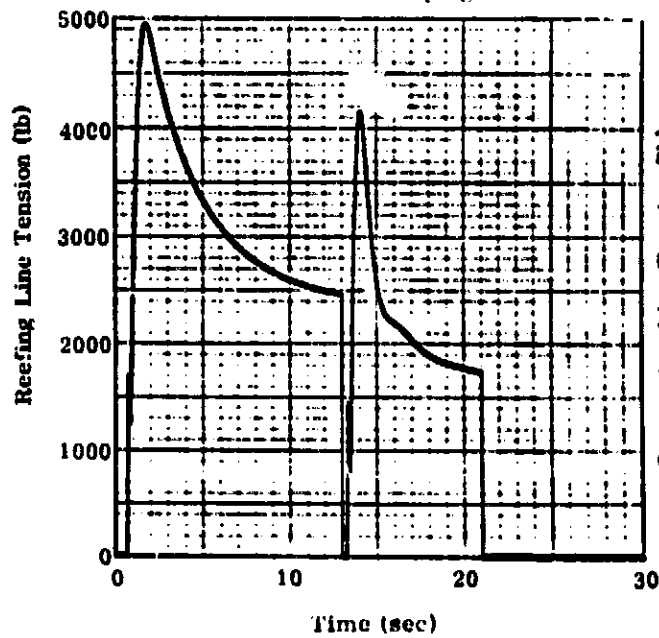
REFERENCES

3-1. McVey, D. F., and Wolf, D. F., "Analysis of Deployment and Inflation of Large Ribbon Parachutes," _Journal of Aircraft_, Vol. 11, No. 2, Feb. 1974, pp. 96-103.

3-2. Maydew, R. C. and Johnson, D. W., "Supersonic and Transonic Deployment of Ribbon Parachutes at Low Altitudes," _Journal of Aircraft_, Vol. 9, No. 7, July 1972, pp. 497-502.

3-3. Holt, I. T., "Design and Development of a Heavy Duty 76-ft Ribbon Parachute," _Proceedings Aerodynamic Deceleration Conference_, FTC TR 69-11, 1969, pp. 69-72.

3-4. Brown, W. C., et al., "Summary Report — Solid Rocket Booster Recovery Concept, 146-In. Diam.," ASD-ASTN-1816, Teledyne Brown Engineering, July 1974.

3-5. Holbrook, J. W., "Sandia Corporation Pressure and Disreefing Test of Model Parachutes in the Vought Systems Division Low Speed Wind Tunnel," Report No. LSWT 445, LTV Aerospace Corp., September 1974.

3-6. Utreja, L. R., "Wind Tunnel Test of the Space Shuttle Solid Rocket Booster Drogue Parachute System," Northrop Services Inc., TR-230-1342, Sept. 1974.

SECTION 4

PARACHUTE STRESS ANALYSIS

SUMMARY OF FACTORS OF SAFETY ON DROGUE AND MAIN PARACHUTES

This table summarizes the results of the CANO structural analyses conducted on both the drogue and main parachutes. If, as indicated on the drawings, the intent is to have a factor of safety of 3.0 in the parachute design, this goal has been met in all areas but the suspension lines of the drogue chute. In fact, the analysis indicates that the strength of the horizontal ribbons in the drogue and the main chutes as well as the material strength in the radials of the main chute could be reduced substantially with some associated weight savings.

SUMMARY OF FACTORS OF SAFETY ON DROGUE AND MAIN PARACHUTE

	Minimum Factors of Safety in		Factors of Safety in	
	Radial Elements	Horizontal Elements	Suspension Lines	Reefing Lines
Drogue Parachute				
Fully inflated	3.3	4.9	2.9	-
Reefed (0.80)	3.4	4.9	2.9	7.4
Main Parachute				
Fully inflated	4.9	9.5	3.0	-
Reefed (0.464)	4.9	7.6	3.1	3.9
Reefed (0.18)	4.9	7.4	3.1	7.0

NOTES:

1. Factors of safety are based on rated material strengths.

2. All joint efficiencies were assumed to be 100%.

3. Drogue parachute riser load was 229,750 lb.

4. Main parachute riser load was 132,833 lb.

THE CANO COMPUTER PROGRAM

CANO is a parachute structural analysis code which was developed by the Northrop Corporation, Ventura Division, under a NASA contract. The program predicts the internal loads and parachute shape resulting from a specified riser load and applied pressure distribution. The amount of detail in the analysis is governed by the number of elements used to model the parachute structure. Present versions of the program allow the use of up to 300 elements. Various elements, such as horizontal ribbons, sails, skirt bands, vent bands, and radial tapes, are analyzed as deformable membranes. Nonlinear material properties are modeled in a piecewise linear fashion.

Although the code performs a static analysis of the modeled structure, our use of the code has, to some extent, taken into account the dynamic response of the parachute. This follows from the use of peak riser loads predicted by DYNAFLATE (see page 2-16) as input in the CANO analysis. The assumption that all meridonal loads are reacted by the radials means simply that the true effect of vertical tapes cannot be determined. The strengths of adjacent verticals are lumped into the radial strengths in the computer simulation of the structure. This provides a reasonable approximation to meridional stiffness but does nothing in the way of predicting the effect of the verticals on the configuration of and loads in the horizontals.

THE CANO COMPUTER PROGRAM

Capabilities

Structural Idealization of

Horizontal ribbons

Skirt bands

Vent bands

Vent lines

Radial tapes

Sails

Reefing lines

Suspension lines

Nonlinear Material Characterization

Prediction of Internal Load Distribution
and Equilibrium Shape

Limitations

Static Analysis

Model Assumes that All Gores are
Identical

No Horizontal Variation in Pressure

All Meridional Loads Reacted by Radials

EXAMPLE OF CANO MODEL OF TYPICAL RIBBON PARACHUTE GORE

This typical gore model illustrates the basic procedure used in discretizing the drogue and main parachutes for CANO analysis. The number of finite elements used is determined by the analyst. In the case illustrated, as well as in the main and drogue parachute analyses, each horizontal ribbon was modeled as one element. Rated strengths of the materials were used as input to the code for all elements. Joint efficiencies were considered to be 100 percent throughout the analyses. As indicated in the illustration, radial strengths are input as total load capacity, while horizontal strengths are input in load per inch of element width. Where appropriate, the radial strengths include the strength of two adjacent verticals. The first and last element in the gore must be located at the top edge of the vent band and the bottom edge of the skirt band, respectively. Furthermore, the width of these two elements is specified as twice their actual width.

It may be seen that the elements are numbered in sequence from the vent band to the skirt band. This is opposite to the convention originally used in CANO. This revision was made so that CANO input would follow the numbering convention commonly used on parachute drawings.

EXAMPLE OF CANO MODEL OF TYPICAL RIBBON PARACHUTE

Element No.	Element Width (in.)	Element Length (in.)	Radial Strength (lb.)	Horiz. Strength (lb./in.)
1	4.660	2.88	13000	4392
2	2.645	3.76	13000	1323
3	2.645	4.40	13000	1323
4	2.645	5.04	17000	1323
5	2.645	5.68	17000	1323
6	2.510	6.32	17000	1191
7	2.393	6.90	17000	1254
8	2.393	7.48	17000	1254
9	2.393	8.06	17000	1254
10	2.393	8.64	17000	1254
11	2.393	9.21	17000	919
12	2.393	9.79	17000	919
13	2.393	10.37	17000	919
14	2.393	10.95	17000	919
15	2.393	11.53	17000	919
16	2.393	12.11	17000	919
17	2.393	12.68	17000	919
18	2.393	13.26	17000	919
19	2.393	13.84	17000	919
20	2.393	14.42	17000	919
21	2.393	15.00	17000	919
22	2.393	15.58	17000	919
23	2.393	16.16	17000	919
24	2.267	16.73	17000	662
25	2.074	17.35	17000	722
26	2.015	17.74	17000	744
27	2.015	18.33	17000	744
28	2.015	18.71	17000	744
29	2.015	19.20	17000	744
30	2.015	19.69	17000	744
31	4.030	20.42	17000	744

2.88

0.625 (5) places

0.630 (5) places

0.375 (18 places) 72.0

0.378 (18 places)

2.015 typ.

Element Width

0.125 (1) place

0.125 (1) place

20.42
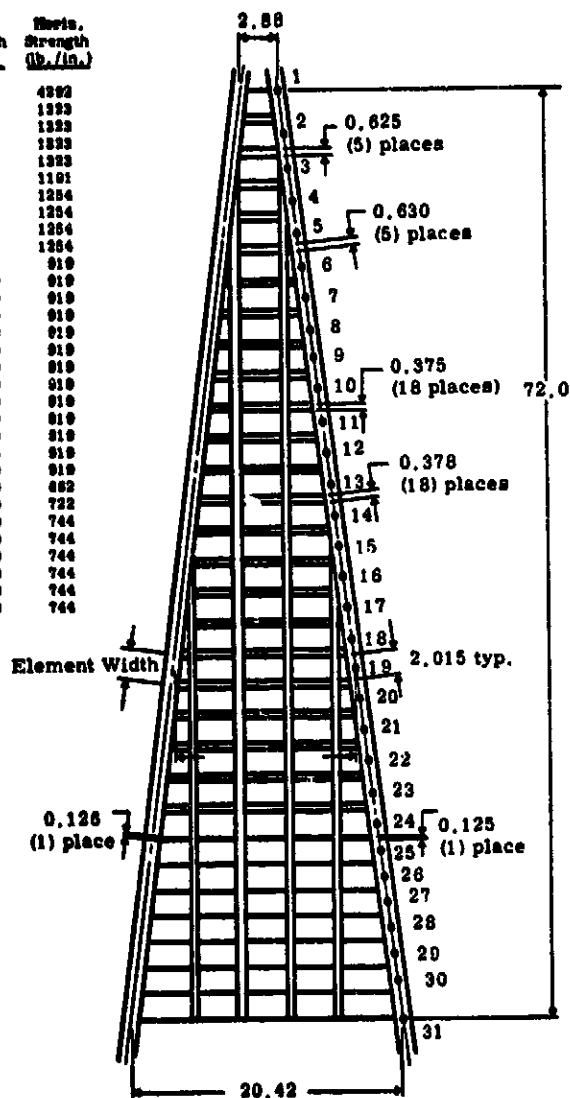
MATERIAL CHARACTERIZATION

Load versus strain information was not available for the vast majority of materials specified in the drogue and main parachute designs. The material characterization used in the CANO analysis was obtained from tests on 52 specimens from ten types of nylon webbing. The nonlinear material behavior was approximated in the piecewise linear manner indicated by the dotted lines. The CANO code has the capability of using up to seven straight line segments to approximate nonlinear material behavior.
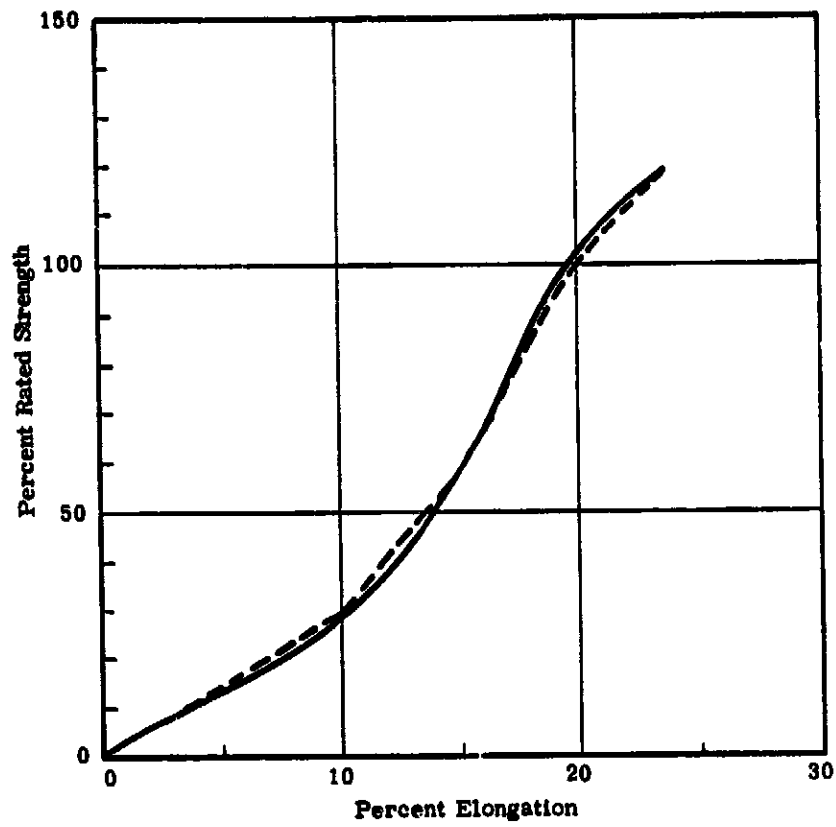
On this and all succeeding curves describing CANO results, the elements are numbered from the vent band to the skirt band. This corresponds to the convention previously described for CANO input.

"Failure index" is defined as load/rated strength. Thus, the failure index defines the proximity of the material to a failure strength. It is implied here that, for the nylon materials used, failure will occur at the rated strength of a material.

These curves present a rather concise, yet complete, picture of the load distribution in the parachute canopy. The discontinuities which exist are due to changes in material strengths and corresponding stiffness changes. An example of this is the effect of the horizontal reinforcement in element 73 which may be observed on this and the following graph.

It may be seen that a considerable variation exists in the value of failure index of the horizontals. This is generally true for the horizontals in both parachutes in the reefed and fully inflated conditions. It is concluded from this that optimum use is not being made of the material for the pressure distribution and riser load under consideration.

For the reefed drogue, lower strength horizontals could be used in all areas of the structure. This conclusion is based on the stated design factor of safety of 3.0 and neglects joint efficiencies, material property degradation due to temperature effects, and other similar considerations. It should also be restated at this point that nylon properties for the materials specified on the parachute drawings were not available and that average properties from tests on numerous types of nylon webbing were used in the analysis. More analyses using load versus strain information for the materials actually specified in the design is recommended prior to a redesign.

The strength of the radials appears to meet the design intent more closely than the horizontal strengths in this case.
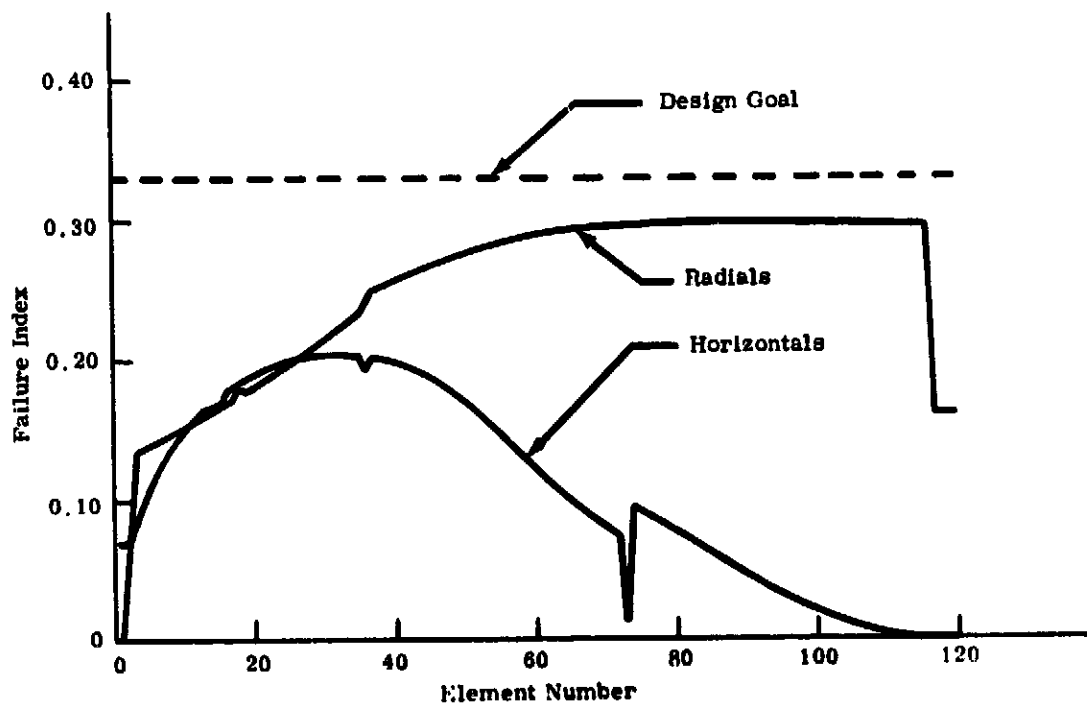
FAILURE INDICES FOR FULLY INFLATED DROGUE PARACHUTE

The maximum values of failure index in both the radials and horizontals are nearly the same as they were for the reefed drogue. The horizontal ribbons are stressed more highly near the skirt and the radials are stressed somewhat less near the vent in this case.

FAILURE INDICES FOR FULLY INFLATED DROGUE PARACHUTE
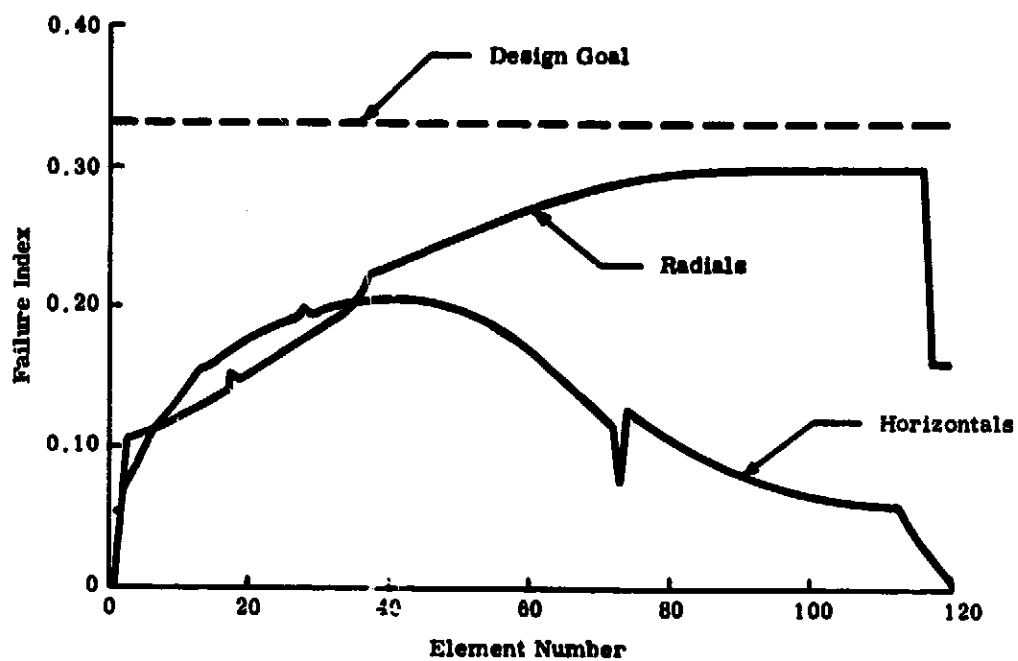
FAILURE INDICES FOR MAIN PARACHUTE WITH REEFING RATIO OF 0.18

The CANO analysis indicates that both the radials and horizontals have been significantly oversized. The riser load for this and the other two inflated stages of the main parachute was 132,833 lb.

FAILURE INDICES FOR MAIN PARACHUTE WITH REEFING RATIO OF 0.18
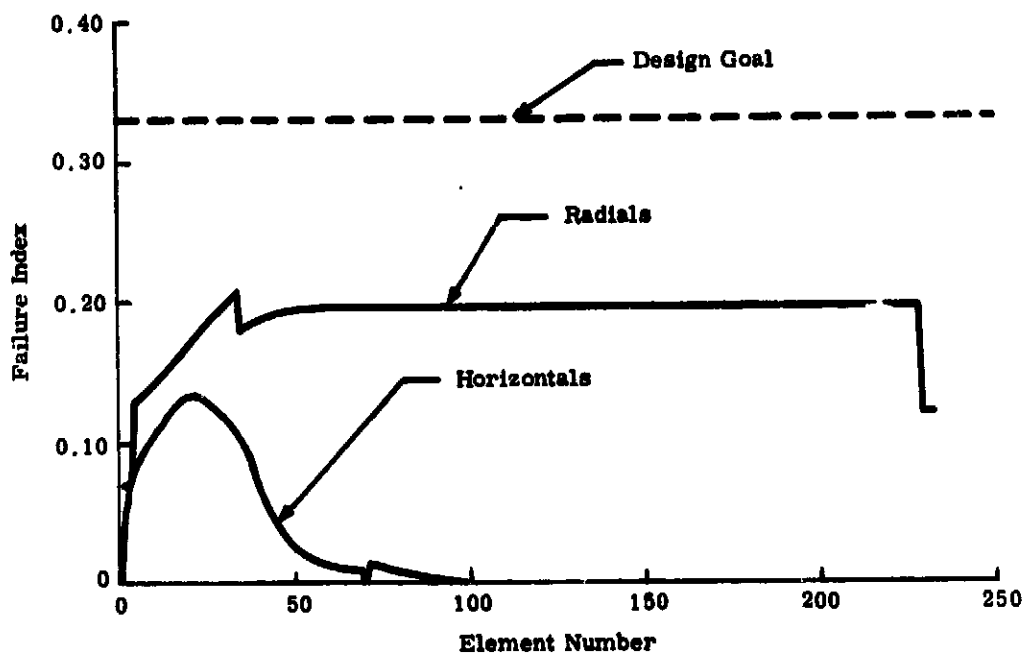
FAILURE INDICES FOR MAIN PARACHUTE WITH REEFING RATIO OF 0.464

The maximum values of failure index are approximately the same as for the case where the reefing ratio was 0.18. Again the analysis indicates that considerable amount of material strength and some associated weight can be cut from the main parachute design.

FAILURE INDICES FOR MAIN PARACHUTE WITH REEFING RATIO OF 0.464
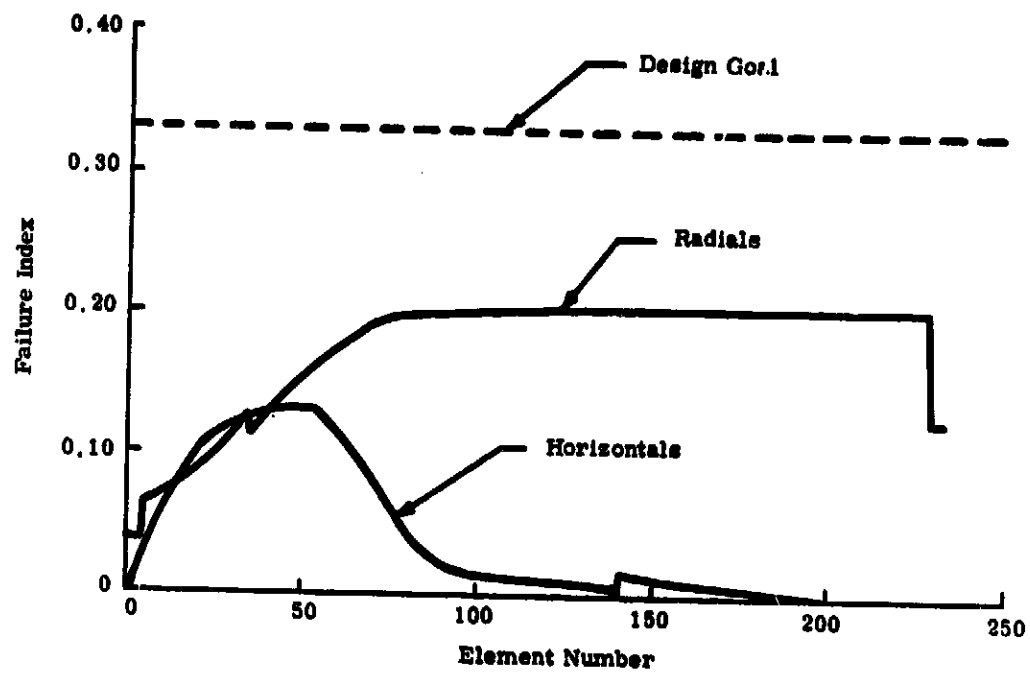
FAILURE INDICES FOR FULLY INFLATED MAIN PARACHUTE

The maximum value of the failure index in the radials is approximately 0.2 as it was in the analysis of the reefed stages. The peak failure index for the horizontal ribbons has dropped from 0.13 for the reefed stages to 0.105 for the fully inflated condition. The analyses for all three inflation conditions thus indicate that the minimum factor of safety in the radials and horizontals is approximately 5.0. The tabulated results presented on page 4-3 indicate that the suspension lines are the weak link in the main parachute as they are in the drogue.

FAILURE INDICES FOR FULLY INFLATED MAIN PARACHUTES
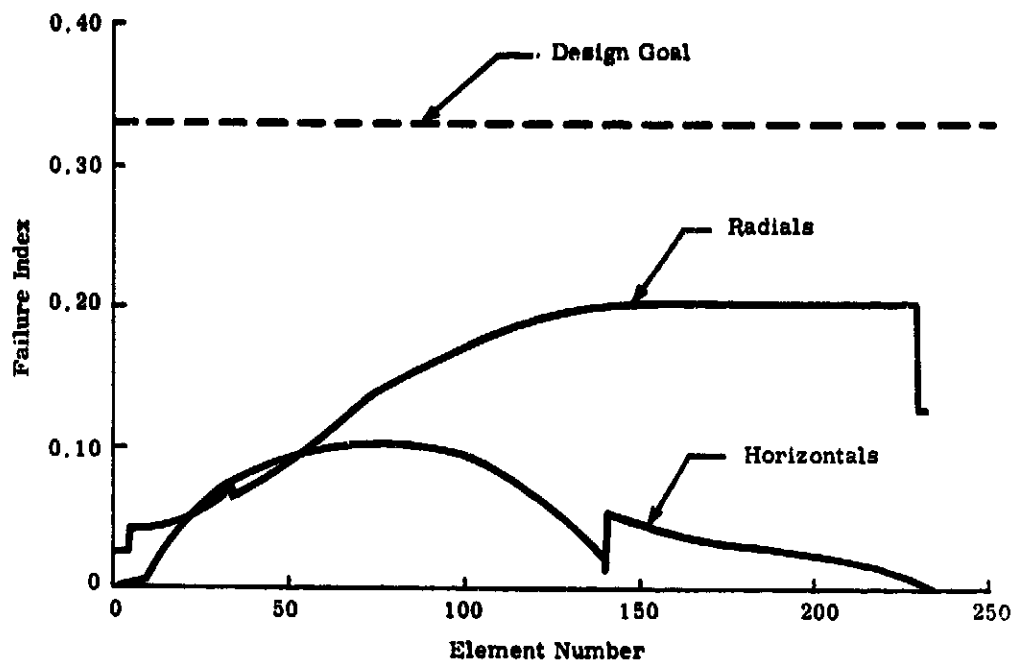
FULLY INFLATED MAIN PARACHUTE CANOPY SHAPE

In addition to calculating load and strain distribution in a parachute, the CANO computer program also determines an equilibrium canopy shape. The predicted main parachute shape for the fully inflated condition is presented here. The ordinate of the graph is the centerline of the canopy. The solid line represents the deformed shape of the radials. The dashed line illustrates the shape of the gore centerline and indicates the amount of gore bulge.

FULLY INFLATED MAIN PARACHUTE CANOPY SHAPE
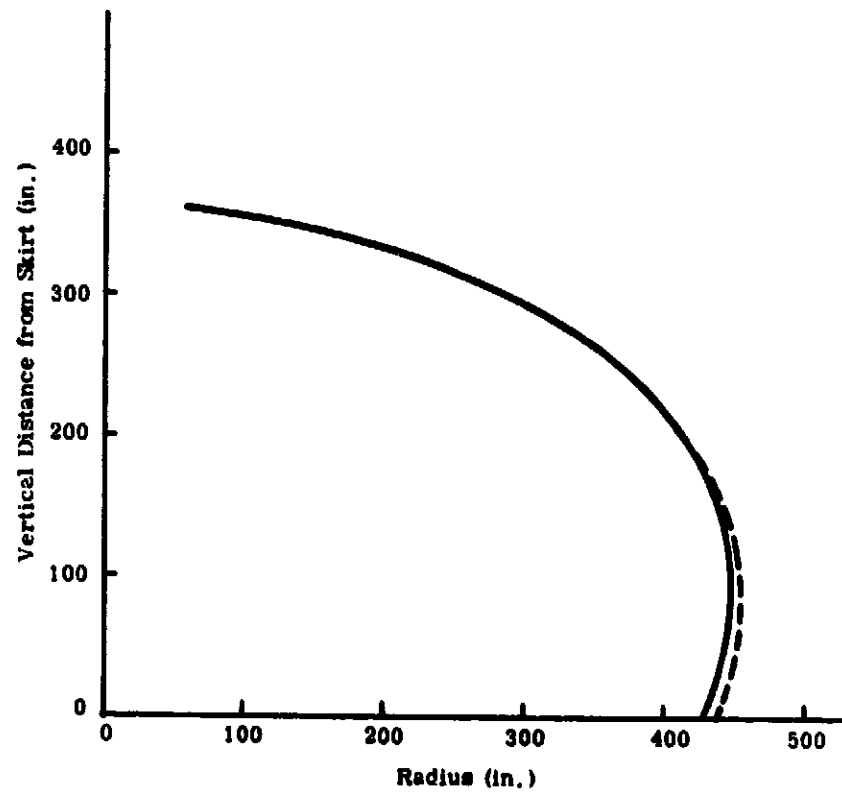
PARACHUTE OPTIMIZATION

Because of the nature of parachute structures, they land themselves well to optimization. A modified version of CANO (called CANOPT) exists in which parachute optimization is attempted. The code attempts to match material strengths to loads in the individual elements. An iterative procedure is carried out until the strength of each element is within a specified limit of the load in the element.

Illustrated here are the results of an attempt to optimize a 14-foot ribbon parachute. The original horizontal ribbon selection resulted in a conservative design in all areas relative to the desired goal. Although the optimized structure does not achieve completely the design intent, it comes far closer to this goal than did the original design. For this parachute, the analysis predicted that a savings of 45 percent in horizontal ribbon weighs could be realized through this optimization. This result assumed that an infinite variety of material strengths were available from which a parachute could be constructed. The weight savings for a buildable chute would be approximately 30 percent.

The large changes in slope between elements 13 and 16 and between elements 20 and 23 are related to large discontinuities in horizontal ribbon strengths specified in the original design. This same effect would be observed at locations of the horizontal reinforcement bands in trying to optimize the drogue and main parachutes.

PARACHUTE OPTIMIZATION
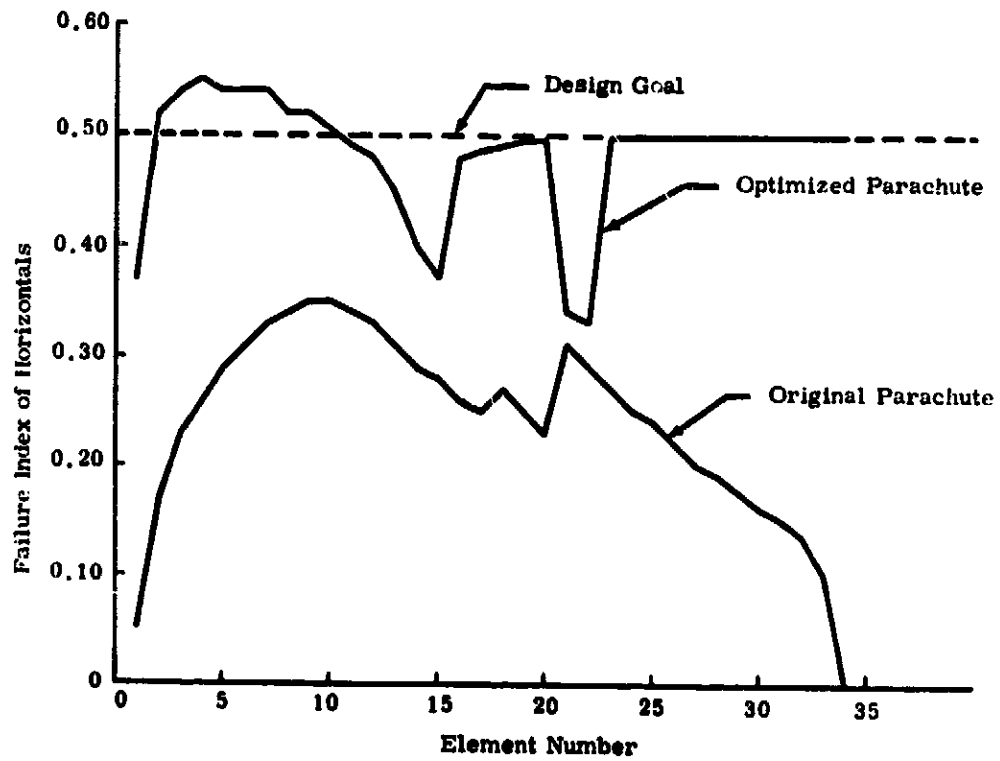
DYNAMIC STRUCTURAL ANALYSIS OF PARACHUTE WITH DYNAPT

DYNAPT is a Sandia Laboratories computer program that calculates the large displacements, stresses, and strains of an inflating parachute. DYNAPT models the parachute as a nonlinear elastic membrane with load carrying ability and, using the parachute materials. A typical output of this code is shown in the figure. Plotted here are the parachute shape, the tension in the radial member, and the pressure loading on the canopy. As the plot shows, there are instantaneous values of these quantities at time equal 1.4.

TIME =1.4000
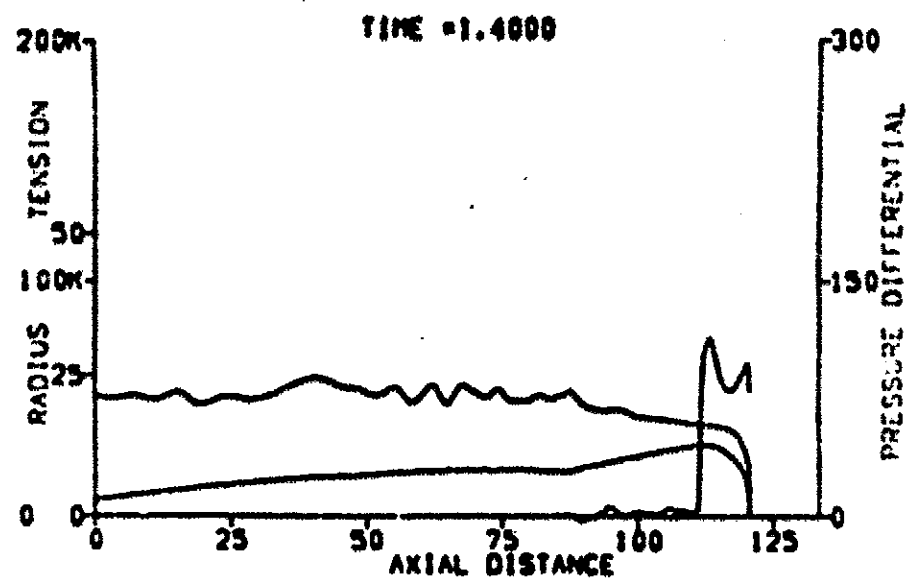
MATERIAL DESCRIPTION USED ON DYNAMIC STRUCTURAL ANALYSIS CODES

The following figures illustrate the piecewise linear models of the stress-strain curves generally used in nonlinear structural analysis computer programs. These graphs very adequately model the textiles typically used in parachute construction. The curves indicate that strain rate effects are of systematic importance in dynamic calculations. Little experimental data currently exist for the high strain rates seen in parachute dynamics.

STRESS-STRAIN CURVE USED BY ADVANCED CODE
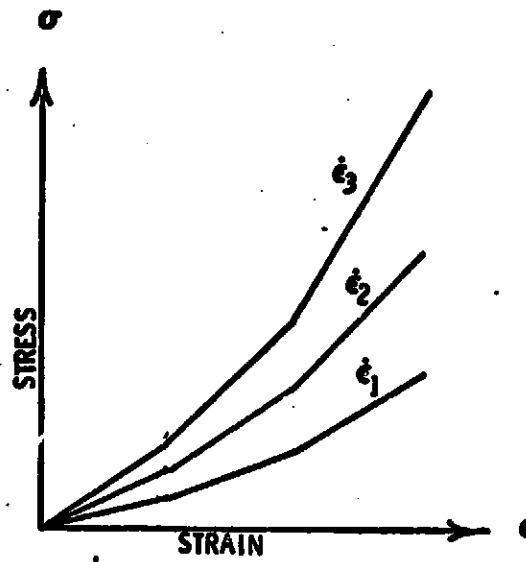
NOTE: $\dot{\epsilon}_1 < \dot{\epsilon}_2 < \dot{\epsilon}_3$

STRESS-STRAIN CURVE ACCEPTED BY DYNAFLATE
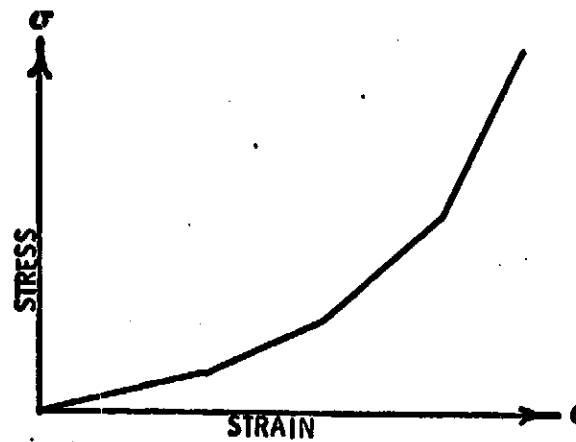
LONG-TERM FATIGUE CYCLE TESTING FOR PARACHUTE MATERIALS

The figure schematically indicates the procedure that should be followed for the testing of materials that are to be used in the sail parachutes. The basic procedure is the same for both types of fatigue testing. The program should include sufficient specimens such that, after a number of cycles, the specimens can be loaded to failure (i.e., breaking). Effort should be made to simulate the actual history seen by a cycled parachute. This would include loading to the maximum stress rates, soaking in sea water, exposure to sunlight, abrasion that would simulate filling, washing, and drying. The results anticipated from such testing also are shown in the figure.

PROPOSED "FATIGUE" CYCLE FOR PARACHUTE MATERIALS
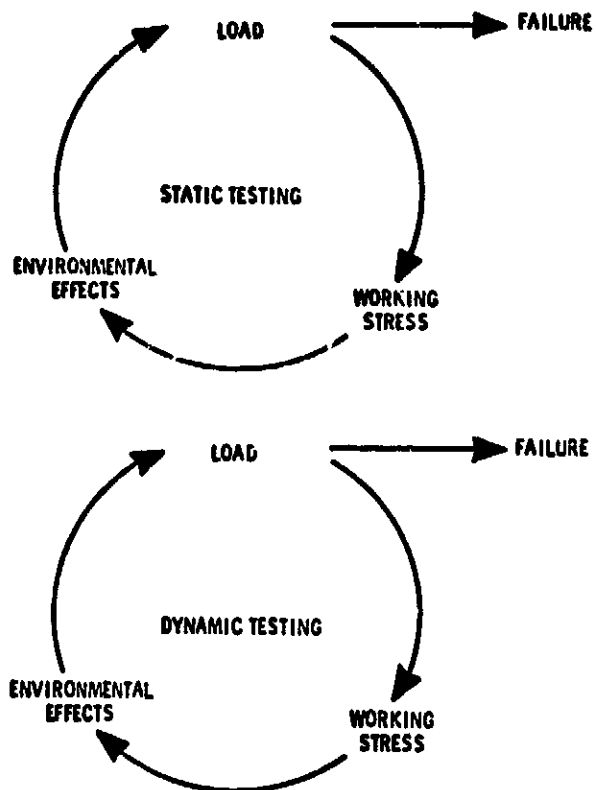
EXPECTED RESULTS FROM MATERIAL TESTS
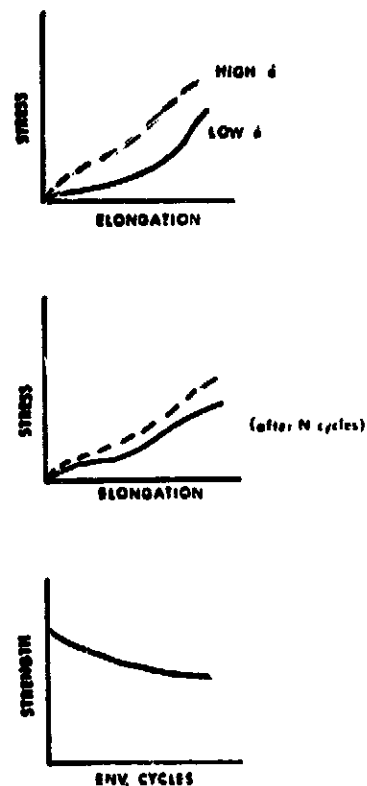
HIGH STRAIN RATE TESTING OF PARACHUTE MATERIALS

The first figure shows typical strain rate effects on nylon fibers. For adequate characterization of this effect in structural analysis computer programs, proper high strain rate tests must be performed. Some of the hardware available to perform such tests are shown in the second figure. All of the methods possible should be evaluated as to cost, availability, and effectiveness before any one of them is chosen.

STRAIN RATE* EFFECTS ON TYPICAL NYLON FIBERS

AVAILABLE DYNAMIC TESTING EQUIPMENT
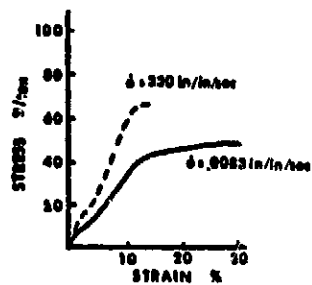
	LOW STRAIN RATE	HIGH STRAIN RATE
BREAKING ELONGATION	30.4	12.7
BREAKING STRENGTH	48.2	65.4
INITIAL MODULUS	350.	1400.
ENERGY TO RUPTURE	103.	52.

*DATA FROM HALL, HIGH SPEED TESTING, VOLUME IV

- DROP TOWER - NASA, SANDIA
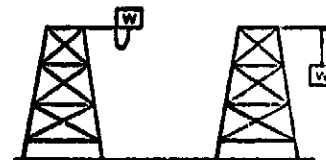
- HIGH G ACTUATOR - SANDIA
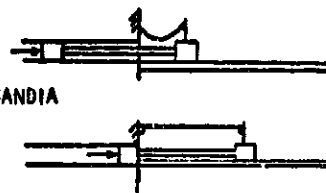
- DROP TABLE - SANDIA
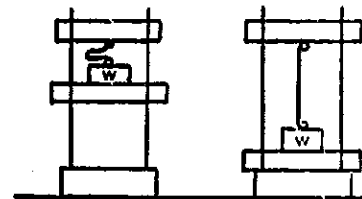
DYNAMIC STRUCTURAL ANALYSIS OF PARACHUTES WITH AN ADVANCED CODE

An advanced computer program is under development that will model the complete three-dimensional structural response of a parachute. Output of this code will define the motion of a parachute gore, as shown in the figure. Stresses, strains, and displacements as a function of time will be computed for radial tapes, horizontal members, and suspension lines.

$t = t_1$

$t = t_2$

4-33
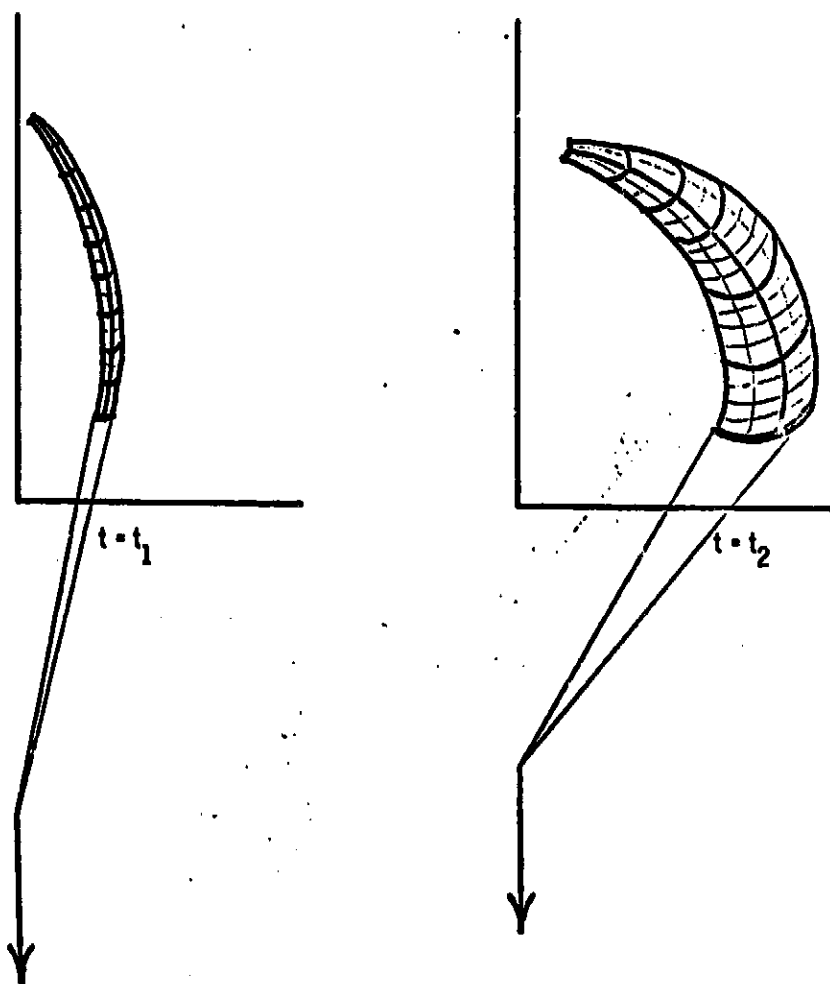
SECTION 5

DROP TEST PROGRAM

BLANK PAGE

IS A PARACHUTE DROP TEST PROGRAM NECESSARY?

The Sandia views on whether a drop test program is a necessary part of the SRB parachute development program were requested. A complete answer to the question can only be stated by evaluating the probable impact on program cost of eliminating drop tests. This was not attempted, but some statements and conclusions about the likely result of eliminating the drop test program are included. These statements are based primarily on experience gained during the development of heavy ribbon parachutes.

IS A PARACHUTE DROP TEST PROGRAM NECESSARY?

- A FLIGHT TEST PROGRAM IS AN ESSENTIAL PART OF THE DEVELOPMENT OF NEARLY ALL STATE-OF-THE-ART RECOVERY SYSTEMS

- THE SRB DROGUE AND MAIN PARACHUTES ARE NOT WITHIN THE DEMON-STRATED STATE-OF-THE-ART

- THE PROBABILITY OF A SUCCESSFUL RECOVERY ON THE FIRST FLIGHT WITHOUT A DROP TEST PROGRAM IS SMALL—LESS THAN 20 PERCENT

- WITHOUT A DROP TEST PROGRAM A PARACHUTE FAILURE ON THE FIRST FLIGHT WOULD ALMOST CERTAINLY BE DUE TO A DESIGN DEFICIENCY RATHER THAN A RANDOM COMPONENT FAILURE

- ALL SYSTEMS IN EXISTENCE AT THAT TIME WOULD HAVE THE SAME DEFICIENCY AND WOULD ALSO FAIL UNLESS REDESIGNED

- THE PRIMARY FAILURE ANALYSIS AND REDESIGN TOOL IN PARACHUTE TESTING IS EXTENSIVE PHOTOGRAPHIC COVERAGE

- PHOTOGRAPHIC COVERAGE FROM BOTH REMOTE AND ONBOARD CAMERAS IS REQUIRED

- GOOD REMOTE COVERAGE FROM CHASE AIRCRAFT AND GROUND STATIONS IS MOST ESSENTIAL

- GOOD REMOTE PHOTOGRAPHIC COVERAGE OF RECOVERY SYSTEM OPERA-TIONS WOULD BE EXTREMELY DIFFICULT DURING SRB FLIGHTS

- THE DATA REQUIRED FOR A SUCCESSFUL REDESIGN WOULD NOT BE AVAILABLE

- TELEMETERED DATA (EVENTS, LOADS, ACCELERATIONS, ETC.) PROVIDE A SECONDARY FAILURE ANALYSIS TOOL

- THE PRIMARY VALUE OF TELEMETRY DATA IS TO VERIFY THE ADEQUACY OF OR ALLOW IMPROVEMENTS ON A SYSTEM WHICH ALREADY WORKS

- A RECEIVING STATION IS REQUIRED TO OBTAIN TELEMETRY DATA

- ONBOARD RECORDED DATA (MEASUREMENTS OR PHOTOGRAPHS) ARE DIFFICULT TO RECOVER IF A PARACHUTE FAILURE OCCURS

- A DEVELOPMENTAL FLIGHT TEST PROGRAM FOR THE SRB RECOVERY SYSTEM IS ESSENTIAL

- EARLY BOOSTER FLIGHTS DO NOT PROVIDE AN ACCEPTABLE ENVIRONMENT FOR DEVELOPMENTAL FLIGHT TESTS

- WITH AN ADEQUATE DROP TEST PROGRAM THE PROBABILITY OF A SUC-CESSFUL RECOVERY ON THE FIRST FLIGHT IS LARGE—80 PERCENT OR GREATER

- DEVELOPMENT OF THE SRB RECOVERY SYSTEM SHOULD NOT BE ATTEMPTED WITHOUT A REASONABLE DROP TEST PROGRAM

SOME PROBLEMS IN PRESENTATION AND DATA QUALITY
IN SATELLITE EXPERIMENTS TO BE CONDUCTED

The first task . . . . present desired to determine is normal to evaluate
. . . . as a part of the trajectory . . . were recorded. It would
. . . . and . . to telemetry and photographic data
. . . . obtained on a test range specially instrumented for para
. . . . Normal flight tests that little or no data would be obtained from a
. . . . flight . . . . event of a failure.

WHAT BOOSTER INSTRUMENTATION WOULD BE REQUIRED IF NO DROP TEST PROGRAM WERE CONDUCTED?

TELEMETRY	TM CHANNELS
STRAIN GAGES	
2 EACH MAIN	6
3 DROGUE	3
BARO SWITCH PRESSURE	1
BARO SWITCH CLOSURE	1
OTHER EVENTS	2
TOTAL	25

REQUIRE
- RECOVERY SHIP FOR CAMERAS
- TM RECEIVER STATION (50 CHANNELS)
- RADAR TRACKING
- REMOTE PHOTO COVERAGE

BOOSTER INSTRUMENTATION REQUIRED
IF NO PARACHUTE DROP TEST PROGRAM IS CONDUCTED

INSTRUMENTATION	COMMENTS
CAMERAS - 8	RECOVERABLE WITH
4 - SIDE VIEW	FLOTATION AND
2 - END VIEW DROGUE	LOCATION GEAR
2 - END VIEW MAIN	

TELEMETRY	TM CHANNELS
3 - AXIS ACCELEROMETERS - 2	6
3 - AXIS GYROS - 2	6

TEST PROGRAM OBJECTIVES

Listed below are the major areas of interest for which a Test Program could provide information. The areas are listed more or less in chronological order than in order of importance. Each of the topics is something that is enough different from the present state of the art that additional data is needed specifically for the SRB. Each area is discussed further on the following page.

TEST PROGRAM OBJECTIVES

1. RE-USE
2. VEHICLE-DROGUE DYNAMICS
3. DROGUE PERFORMANCE
   A. DEPLOYMENT
   B. INFLATION
   C. LOADS
   D. DRAG
4. SINGLE MAIN PERFORMANCE
   A. DEPLOYMENT
   B. INFLATION
   C. LOADS
   D. DRAG
5. MAIN CLUSTER PERFORMANCE
   A. DEPLOYMENT
   B. INFLATION
   C. LOADS
   D. DRAG
   E. STABILITY
   F. DYNAMICS AT IMPACT
6. RE-FURBISH
7. RETRIEVAL

At present, very little is known about the re-use question. The effects of the repeated soaking in salt water and handling between uses need to be investigated. Data need to be gathered to aid in initial design of the system. The facts that scaled data are usable, that tests can be planned using existing hardware, and that inexpensive drops can be made indicate that it would be desirable to start this phase of the testing as soon as possible. Laboratory tests should also be started to aid in interpreting the data from the drop tests.

The need for starting these tests soon can not be over-emphasized.

I. RE-USE

    A. SHOULD BE STARTED ASAP

    B. CAN BE SCALED EASILY

    C. NOT EXPENSIVE

    D. USE EXISTING CHUTES ?

    E. DONE IN CONJUNCTION WITH LAB TESTS

VEHICLE-DROGUE DYNAMICS

... the dynamics ... as large as the SRB ... because of the large ... investigation on as large a scale as possible to make the ... model. Half scale appears to be the largest size practicable.

... program ... early in the entire program because ... results, and could necessitate major changes.

2. VEHICLE-DROGUE DYNAMICS

A. CAN REALISTICALLY ONLY BE DONE
ON A SCALE MODEL

B. SCALE SHOULD BE AS LARGE
AS POSSIBLE

C. 1/2 SCALE (6 FT DIA, 70 FT LONG,
41,000 LB) IS FEASIBLE USING
B52 MOTHER SHIP

D. MUCH SMALLER SCALE WOULD
GIVE QUESTIONABLE DATA

DROGUE PERFORMANCE

As mentioned previously, deployment from a side-on booster presents special problems for the drogue parachute system. Deployment tests should be made with full scale parachutes and the half scale vehicle used in the scale drogue tests. This would help determine the scale effects and aid in interpretation of the earlier scale tests.

Inflation tests should be made with the heaviest weight possible in order to obtain inflation times near those expected in the final configuration. An increase in speed may be necessary to obtain realistic inflation times.

To get load information, speeds will have to be increased above design speed in order to get peak loads to match those predicted. Again, the weight of the vehicle should be as high as possible. Overtesting is desirable to prove that an adequate design factor is attained.

Drag information can be obtained on the above tests, so no special tests need be made to get final drag data.

3. DROGUE PERFORMANCE

   A. DEPLOYMENT
      (1) FULL SCALE, USING 6 FT DIA VEHICLE
             USED FOR VEHICLE-DROGUE DYNAMICS
      (2) CAN BE USED TO CHECK SCALE EFFECTS

   B. INFLATION
      (1) USE HEAVIEST WT POSSIBLE
      (2) DONE AT DESIGN SPEED AND
             HIGHER TO GET LOAD

   C. LOADS
      (1) HEAVIEST WEIGHT
      (2) INCREASED SPEED TO GET 1ST STAGE
      (3) ALTER REEFING FOR FULL OPEN LOAD
      (4) NEED TO RELY ON COMPUTER TO
             PREDICT LOADING
      (5) OVERTEST 1ST AND 2ND (?) STAGES

   D. DRAG
      (1) GET DATA ON ABOVE TESTS
      (2) NEED TO KEEP WEIGHT UP

SINGLE MAIN PERFORMANCE

Some tests of a single main parachute need to be made before cluster testing is performed. If the appropriate weight is used, deployment, inflation, and load tests are essentially fullscale. Reefing would not need to be altered for attaining proper disreefing loads.

These tests of a single main would give good baseline data for the follow-on cluster testing.

4. SINGLE MAIN PERFORMANCE

    A. DEPLOYMENT

        (1) WT OF 53,000 + LB. IF POSSIBLE

        (2) VEHICLE SHAPE NOT IMPORTANT

    B. INFLATION - SEE ABOVE

    C. LOADS   - SEE ABOVE

    D. DRAG   - SEE ABOVE

MAIN CLUSTER PERFORMANCE

In the use of such a large parachute in a cluster at the speed involved, deployment and initial inflation are the biggest problems anticipated. Testing should be done with the proper pack configuration. While vehicle shape is relatively unimportant, high weight is of prime concern.

Using data from the single chute tests, the reefing can be altered to obtain proper loading for the second stage loads.

Drag and stability data can be gathered during the above tests. Terminal speed will be low due to the low weight, but qualitative information can be obtained on stability.

If drops could be made over water, impact dynamics might be studied. Because of the velocity being wrong and a suitable test site not being readily available, it is felt that impact dynamics testing should not be done in conjunction with the above tests.

5. MAIN CLUSTER PERFORMANCE

    A. DEPLOYMENT

        (1) NEED FOR PACK SHAPE TO BE RIGHT

        (2) VEHICLE SHAPE NOT IMPORTANT

        (3) HEAVIEST WEIGHT AVAILABLE

    B. INFLATION - SEE ABOVE

    C. LOADS   - SEE ABOVE

        (4) DESIGN SPEED + 1ST STAGE

        (5) ALTER REEFING FOR 2ND STAGE

    D. DRAG

        (1) DATA FROM TESTS ABOVE

        (2) NEED TO KEEP WEIGHT HIGH

    E. STABIL'TY

        (1) LINE LENGTH

        (2) COMPARE TO SINGLE CHUTE

    F. DYNAMICS AT IMPACT

        (1) WRONG SPEED

        (2) NEED FOR WATER RANGE OF GOOD DEPTH

REFURBISH

Information required on refurbishment and refurbishment methods could be obtained in connection with the previously mentioned re-use tests. This would give early data to aid in design.

Refurbishment data could also be obtained in connection with all other parts of the drop test program. Requirements for the extent of refurbishment would be generated during the entire program.

RETRIEVAL

Because of the problems involved with water impact site selection, separate retrieval tests should be conducted. Refurbishment data could also be obtained during these tests.

6. RE-FURBISH

  A. COMBINE WITH RE-USE TESTS

  B. COMBINE WITH ALL PARACHUTE TESTS

  C. COMBINE WITH RETRIEVAL TESTS

7. RETRIEVAL

  A. LIMITED COMBINATION WITH
    OTHER TESTS

  B. SET UP SEPARATE TEST

TEST PROGRAM

This page and the one following outline the recommended test program in terms of number of tests of each type outlined previously. The number of tests indicated represents the minimum number needed to gather the required information if every test is successful and fully valid. The recommended program number of tests is given and is based on past experience and an engineering judgment of the possible problems that will probably occur and the need for design changes and re-tests.

Each objective has been discussed in more detail earlier, so only a few short remarks are included here of pertinent details for each type of test.

As can be seen, the largest ratio of planned tests to minimum tests is in the vehicle-drogue dynamic testing. This is because there are many unknowns in this phase and many problems are probable.

TEST PROGRAM

OBJECTIVE	REMARKS	MINIMUM NUMBER	PROGRAM NUMBER
RE-USE	KEEP CHEAP, SIMPLE, USE AVAILABLE A/C, MAYBE AVAILABLE CHUTES	10	15
VEHICLE-DROGUE DYNAMICS	1/2 SCALE, B52 "MOTHER SHIP," HIGH ALTITUDE	1	4
DROGUE PERFORMANCE	FULL SCALE, USE 6 FT VEHICLE FOR DEPLOYMENT, HEAVY VEHICLE, DESIGN SPEED	1	2
	HEAVY VEHICLE, DESIGN REEFED LOAD	1	2
	HEAVY VEHICLE, DESIGN FULL OPEN LOAD	1	3
	HEAVY VEHICLE, OVERTEST	2	3
	MIN Q	1	1
SINGLE MAIN PERFORMANCE	53,000 LB VEHICLE,	1	3

No tests are shown for the refurbish area because these data can be obtained from all the other tests and no special tests are necessary.

Question marks are shown for the stability, impact dynamics and retrieval tests because no recommendation has been made as to the best way to accomplish these tests and little is known about the kinds of information needed or the problems anticipated. More study is needed in these areas before a specific recommendation can be made. Our past experience in most of these areas is very limited.

OBJECTIVE	REMARKS	MINIMUM NUMBER	PROGRAM NUMBER
MAIN CLUSTER PERFORMANCE	PACK SIZE RIGHT, IF POSSIBLE, HEAVY VEHICLE, DESIGN SPEED DEPLOYMENT	I	3
	HEAVY VEHICLE, DESIGN LOAD REEFED	I	2
	HEAVY VEHICLE, DESIGN OPEN LOAD	I	2
	HEAVY VEHICLE, OVERTEST	I	I
	STABILITY, DYNAMICS AT IMPACT	?	?
RE-FURBISH	COMBINE WITH ABOVE TESTS, RE-USE	0	0
RETRIEVAL	COMBINE WITH RE-FURBISH, AND STABILITY, DYNAMICS ?	?	?
	TOTAL PROGRAM WITHOUT RE-USE	12+	26+

TEST PROGRAM PROPOSALS

This is a comparison of the three test program proposals that were available at the time of this progress report. The "PIONEER" proposal was made at the briefing at the Marshall Space Flight Center by representatives from the Pioneer Parachute Company. The "MSFC" proposal was made at that time by MSFC representatives. The "SANDIA" proposal represents the current Sandia plan.

Sandia feels that scale drogue tests are the only way to obtain meaningful data on vehicle-drogue dynamics. This is felt to be one of the significant problem areas and could drastically affect the overall design. Confirmation of predicted results is necessary in order to proceed with the final design.

The additional data that could be gathered by scale main testing is not felt to be worth the additional cost. The only way such testing would be cost effective is if existing parachutes and hardware could be used to gather early data.

A meaningful "system" test is very difficult to devise until the first real system is used. A system test as a "demonstration" might be useful.

Re-use tests are proposed here primarily because they could be done quickly at small cost and the data are needed very early in the program to aid in determining adequate design factors.

TEST PROGRAM PROPOSALS

TYPE OF TEST	PIONEER	MSFC	NEW	COMMENTS
SCALE DROGUE	0	0	4	BEST WAY TO GET VEHICLE-DROGUE DYNAMICS
DROGUE	12	8	11	MAY NOT NEED SO MANY
SCALE MAIN SINGLE	0	3	0	NOT NECESSARY
SCALE MAIN CLUSTER	0	2	0	NOT NECESSARY, UNLESS STABILITY BECOMES A PROBLEM
MAIN SINGLE	6	5	3	ONLY SO MUCH CAN BE LEARNED FROM SINGLE CHUTE
MAIN CLUSTER	5	2	8	MUCH TO BE LEARNED IN LARGE CLUSTER AREA
"SYSTEM"	4	1	0	CAN'T CONDUCT REALLY MEANINGFUL "SYSTEM" TEST
TOTAL	27	21	26	
RE-USE	0	0	15	DATA NEEDED ASAP

TEST AIRCRAFT CAPABILITY AND AVAILABILITY

This is a review of aircraft capability and availability as determined from discussions with personnel at Edwards AFB and El Centro NAF.

Since those discussions, a significant change in C-5 capability has been proven and demonstrated. Weights of 80,000 pounds or over have been dropped. This changes the picture considerably, and more details should be obtained before final plans for the test program are made. At the time of this report, the B-52 "mother Ship" at Edwards looked most promising. There was some interest at Edwards in an advanced "Mother Ship".

TEST AIRCRAFT CAPABILITY AND AVAILABILITY

AIRCRAFT TYPE	CAPABILITY					AVAILABILITY
	WEIGHT-LB	LENGTH	DIAMETER OR W, H	ALTITUDE	SPEED	
C-130E	30,000	28 FT	8 FT	25,000 FT	160 KCAS	GOOD
C-130H	50,000	28 FT	8 FT	25,000 FT	250 KCAS	POOR, NOT AIR DROP CONFIGURED OR HAVE "E" ENGINES
C-5	41,000	28 FT	9 FT	25,000 FT	250 KCAS	VERY POOR, USED HEAVILY NOW
B52 (WEIGHT LIMITED)	25,000	25 FT	6 FT	45,000 FT	200 TO 300 KCAS	GOOD, ONE AT EDWARDS AFB
B52 (NOT WT LIMITED)	50,000	25 FT	6 FT	45,000 FT	200 TO 300 KCAS	POOR, HAVE TO GET ONE AWAY FROM SAC
B52 MOTHER SHIP"	52,000	52 FT	" 7 FT	45,000 FT	200 TO 300 KCAS	NOW AT EDWARDS, NASA USING FOR X-24B
NEW C-5 "MOTHER SHIP"	160,000?	140 FT?	12 FT?	45,000 FT?	200 TO 250 KCAS	#3 COULD BE MADE AVAILABLE, LONG TERM PROJECT, COST SHARING NEEDED

TEST AIRCRAFT COMMENTS

Based on the previous capability and availability information and the comments provided here, the B-52 "Mother Ship" was picked at the time as the best test aircraft to use.

The fact that the C-5 has been proven to 80,000+ pounds now may alter that decision. Availability may still be a problem area.

The "virtus" of Conway has now been abandoned, and the 747 has been picked to do the horizontal test work with the shuttle. This fact has probably discouraged use of a C-5 mother ship.

The fact that the high altitudes required are within routine operation range of the B-52 and are a difficult, nonstandard operation for the C-5 may still make the B-52 the best choice, but additional information does need to be obtained.

TEST AIRCRAFT COMMENTS

C-130
- WOULD NEED H MODEL, NOT READILY AVAILABLE
- NOT PROVED OVER 28 FT LENGTH
- NONSTANDARD OPERATION ABOVE 20,000 FT

C-5
- COULD GO TO 85,000 LB WITH 20-25 DROP PROGRAM
- COULD GO TO 100 FT LENGTH WITH DEVELOPMENT PROGRAM
- AVAILABILITY POOR, HEAVILY COMMITTED

B-52
(STANDARD)
- HIGH ALTITUDE OPERATION ROUTINE
- WEIGHT LIMITED TO 25,000 UNLESS GET ANOTHER A/C COMMITTED

B-52
"MOTHER SHIP"
- VERY VERSATILE
- AVAILABLE, NOW USED BY NASA
- 70 FT LENGTH REASONABLE WITH MINIMUM EFFORT
- 8 FT DIAMETER REASONABLE
- NOW INSTRUMENTED, CAMERAS, ETC.

C-5
"MOTHER SHIP"
OR "VIRTUS?"
- EXTREMELY VERSATILE (FULL SCALE NOT UNTHINKABLE)
- #3 A/C COULD BE USED, NOT NOW COMMITTED
- LONG-TERM PROJECT, NEEDS MUCH COORDINATION AMONG
  MANY AGENCIES, COST SHARING, (SHUTTLE HORIZONTAL TESTING?)

DROP TEST LOADS PROGRAM GROUND RULES

The basic ground rules used to simulate drop test loads for the SRB parachutes were to use accurate and reliable test methods. The objectives were to minimize the number of tests and to eliminate test failures.

Use of a B-52 Mother Ship drop aircraft was assumed because it can drop a heavy 50,000 pound test vehicle at the required parachute deployment dynamic pressures over a wide altitude range. The preferred drop method is to fly the B-52 at the required parachute test dynamic pressure and to deploy the test parachute immediately upon release from the aircraft. This is essentially the method used to test the Sandia 76-foot parachute. As an alternate test method to be used when a vertical trajectory is required to reduce test vehicle deceleration, a programmer chute would be deployed upon release. This chute would provide the proper terminal conditions for a timer deployment of the test parachute. One of these test methods was used for all of the drop tests simulated in the following pages.

## DROP TEST LOADS PROGRAM GROUND RULES

- DROP AIRCRAFT — B-52 "MOTHER SHIP"

- DROP VEHICLE — 50,000 POUND STABLE VEHICLE

- PREFERRED DROP METHOD — FLY B-52 AT OR NEAR REQUIRED ALTITUDE AND DYNAMIC PRESSURE

  — INITIATE HORIZONTAL DEPLOYMENT WITH STATIC LINE OR SHORT TIMER

- ALTERNATE DROP METHOD — INITIATE PROGRAMMER CHUTE DEPLOYMENT WITH STATIC LINE

  — DEPLOY TEST CHUTE IN VERTICAL ATTITUDE WITH TIMER

DROGUE DROP TEST INFLATION LOADS -
LOAD BOTH STAGES IN ONE TEST

In order to minimize the number of drop tests, the possibility of loading both drogue stages to the design load during one test was investigated. A 50,000 pound test vehicle flying in a vertical trajectory at the nominal altitude (19,000 feet) and dynamic pressure (200 lb/ft^2) was assumed at the start of drogue inflation. A 16 percent porosity drogue with no forebody interference was assumed. The maximum predicted inflation load for this configuration was about 280,000 pounds on both stages. In order to obtain design loads on both stages with the lighter weight 50,000 test vehicle, it is necessary to shorten the drogue reefing time. The first attempt with a 2 second reefed time delay shows that design load is achieved on the first stage but not on the second. A reefing time of 1 second is required to achieve the design load on both stages. Unfortunately, the 1 second reefing time is so short that a small error in the predicted first stage inflation time could cause a large overload on the second stage. For this reason, achieving the design load on both stages of the drogue during one test is not considered possible.
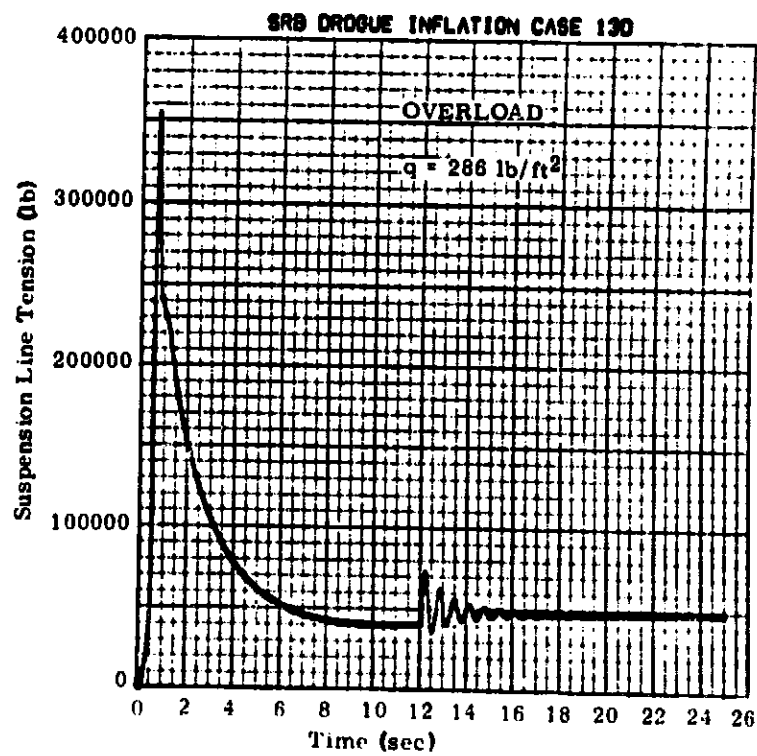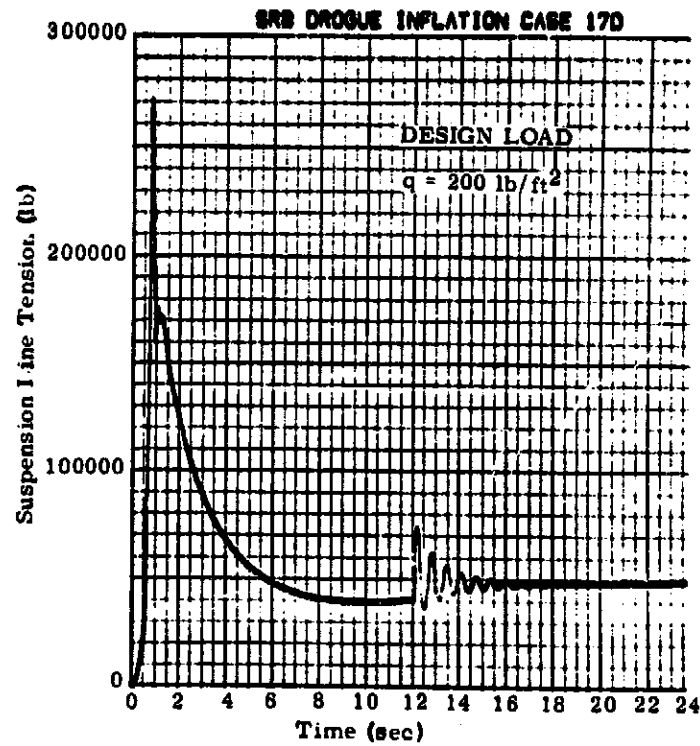
DROGUE DROP TEST INFLATION LOADS -
LOAD BOTH STAGES IN ONE TEST

SRB DROGUE INFLATION CASE 060

SRB DROGUE INFLATION CASE 060
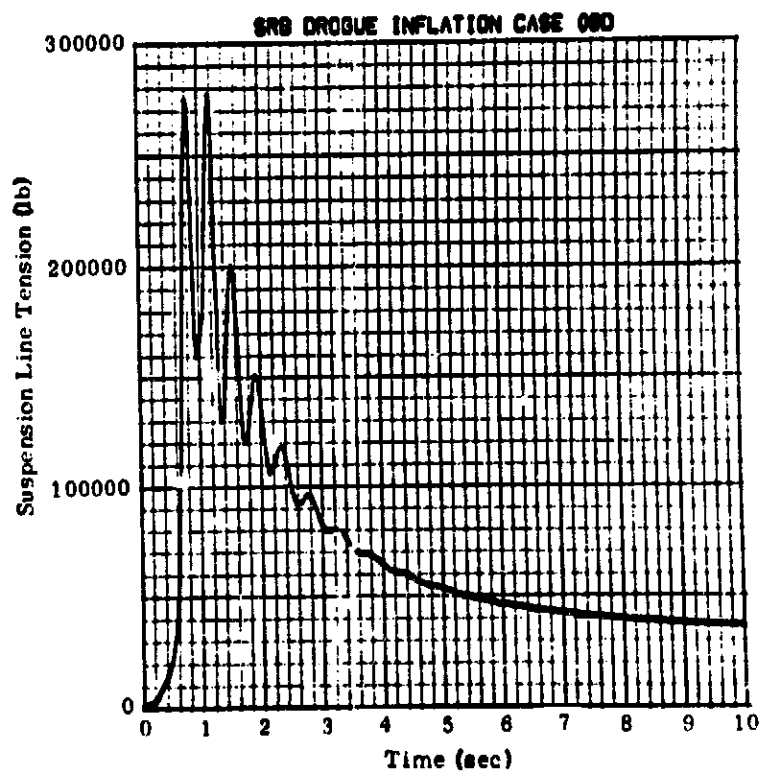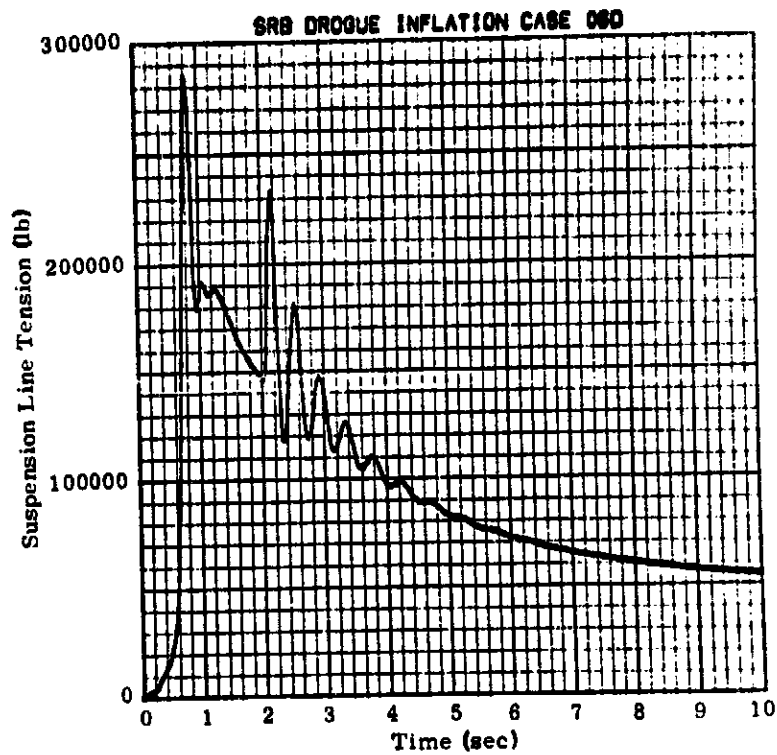
DROGUE DROP TEST INFLATION LOADS -
REEFED STAGE LOADS

Because design loads on both stages of the drogue chute could not be obtained during a single test, conditions required for loading reefed and full open stages separately were investigated. Deployment of the drogue from a 50,000 pound test vehicle in a horizontal trajectory at an altitude of 20,000 feet was assumed. A horizontal drop was chosen to simplify the drop test procedure as much as possible. Design load for the 16 percent porosity drogue was 280,000 pounds. The design load on the reefed drogue was obtained by deployment at a dynamic pressure of 200 lb/ft^2. A 25 percent overload on the reefed drogue is shown to be possible for a deployment at a dynamic pressure of 286 lb/ft^2.

DROGUE DROP TEST INFLATION LOADS -
REEFED STAGE LOADS

SRB DROGUE INFLATION CASE 170

DESIGN LOAD

$q = 200 \text{ lb/ft}^2$

Suspension Line Tension. (lb)

Time (sec)

SRB DROGUE INFLATION CASE 130

OVERLOAD

$q = 286 \text{ lb/ft}^2$

Suspension Line Tension (lb)

Time (sec)

DROGUE DROP TEST INFLATION LOADS - FULL OPEN LOADS

Design load and overload conditions for the full open drogue are obtained by eliminating the first-stage and allowing the drogue to inflate to a full open configuration immediately. A horizontal drop of a 50,000 pound test vehicle at an altitude of 20,000 feet was again assumed. The design load for the drogue was exceeded slightly at a deployment dynamic pressure of $160 \, lb/ft^2$, and an overload test was simulated by deployment at a dynamic pressure of $200 \, lb/ft^2$.

DROGUE DROP TEST INFLATION LOADS - FULL OPEN LOADS

SRB DROGUE INFLATION CASE 140

Design Load
$q = 160 \, lb/ft^2$

SRB DROGUE INFLATION CASE 160
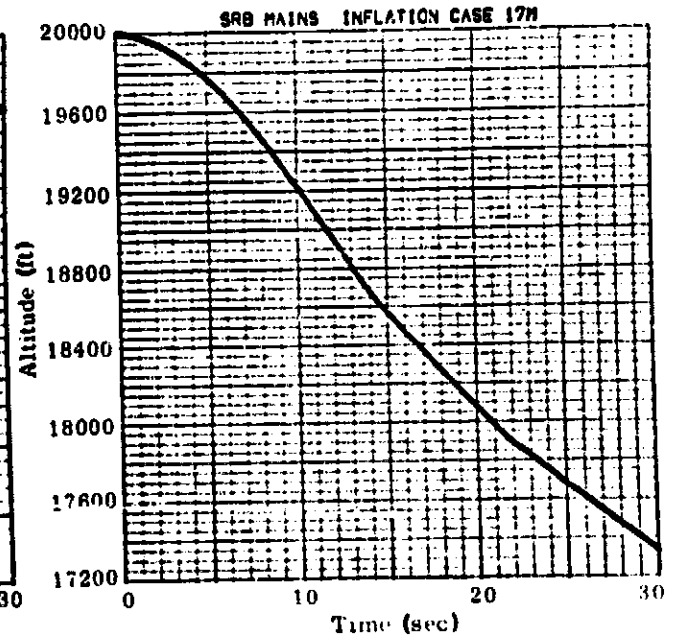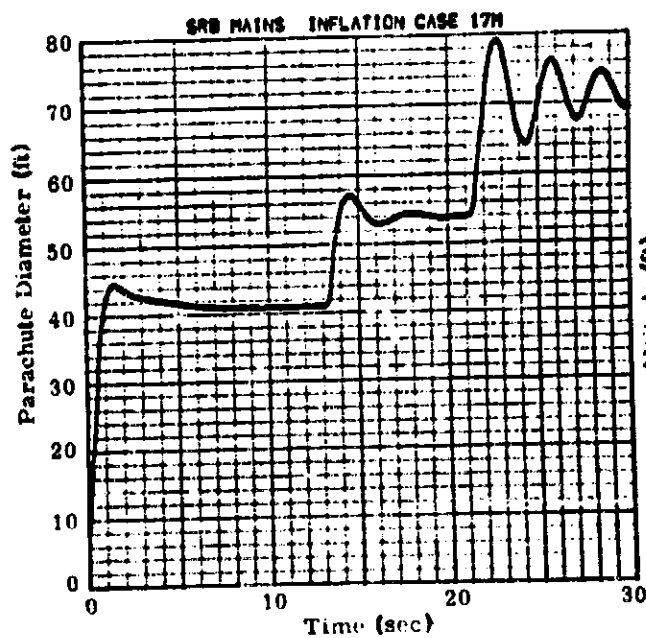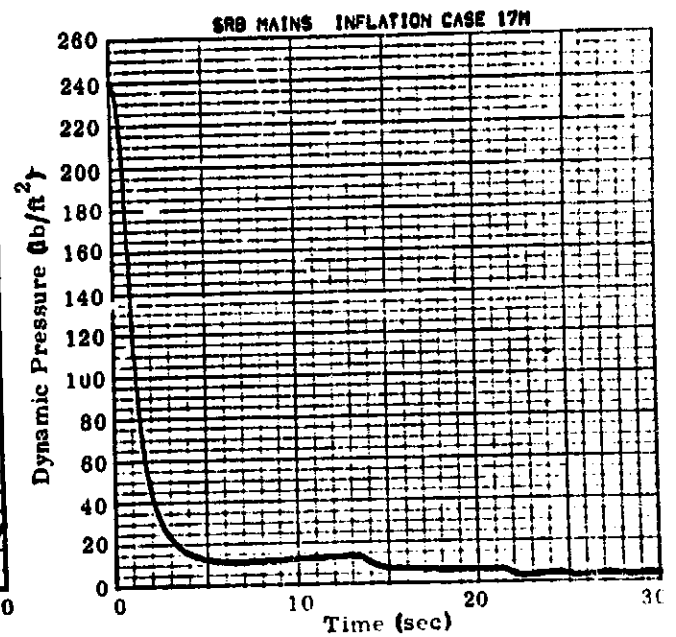
Overload
$q = 200 \, lb/ft^2$
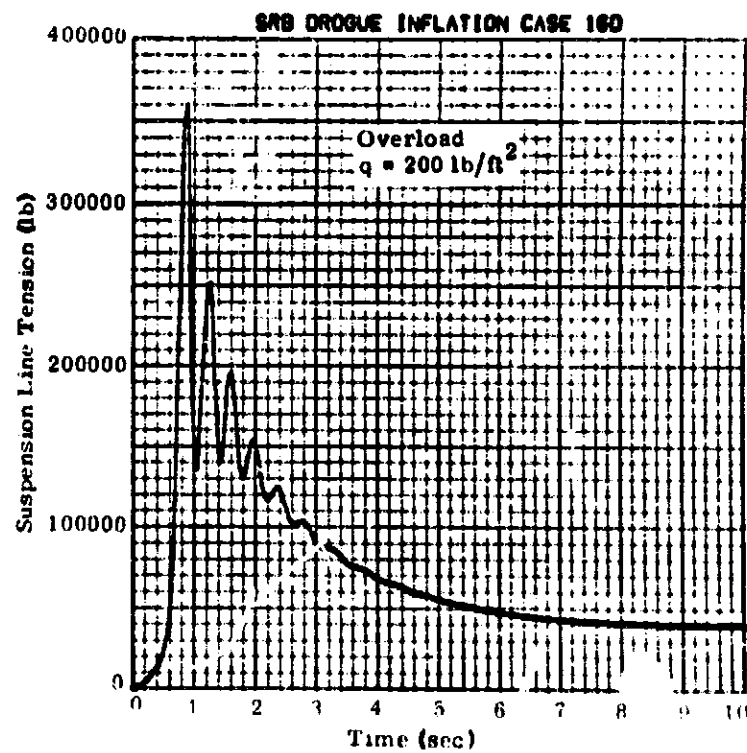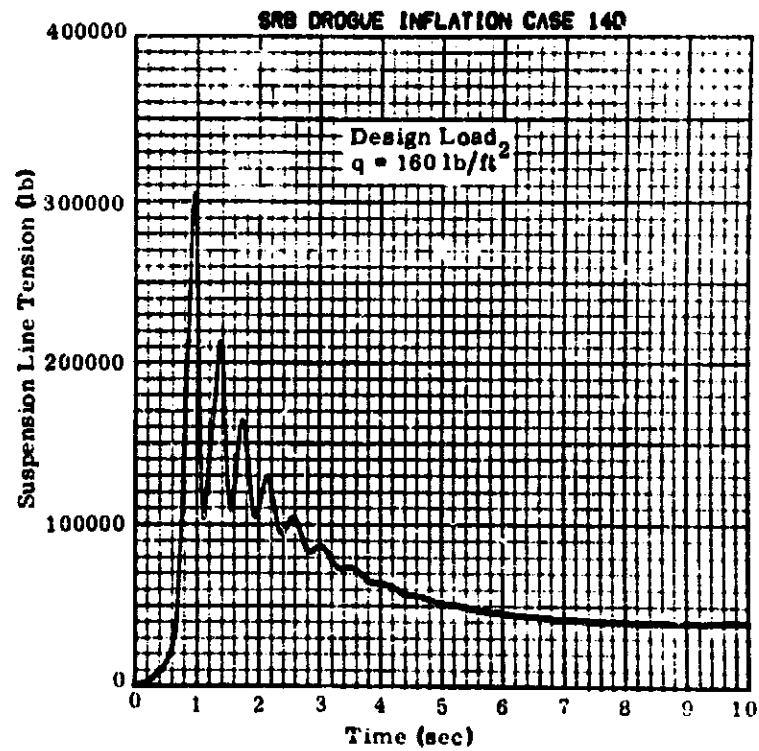
MAIN CHUTE DROP TEST LOADS - DESIGN LOAD
ON CLUSTER FIRST STAGE

For the main chute drop test program, inflation loads were calculated for simulated drop test conditions. The basic philosophy followed was similar to that used for the drogue drop test program; attempts were made to subject the main chutes to design load and overload conditions with the smallest number of tests. A 50,000 pound test vehicle dropped from a B-52 type aircraft was assumed. Simple horizontal deployments were used when possible. The first drop conditions investigated were for deployment of a full main cluster. For a horizontal deployment at an altitude of 20,000 feet and a dynamic pressure of 240 lb/ft^2, the design load of approximately 130,000 pounds per parachute is obtained on the first reefed stage. All three parachutes were assumed to inflate simultaneously. Nominal reefing times used resulted in very low second and third stage loads.

MAIN CHUTE DROP TEST LOADS -
DESIGN LOAD ON CLUSTER FIRST STAGE

SRB MAINS INFLATION CASE 17M

SRB MAINS INFLATION CASE 17M

SRB MAINS INFLATION CASE 17M

SRB MAINS INFLATION CASE 17M
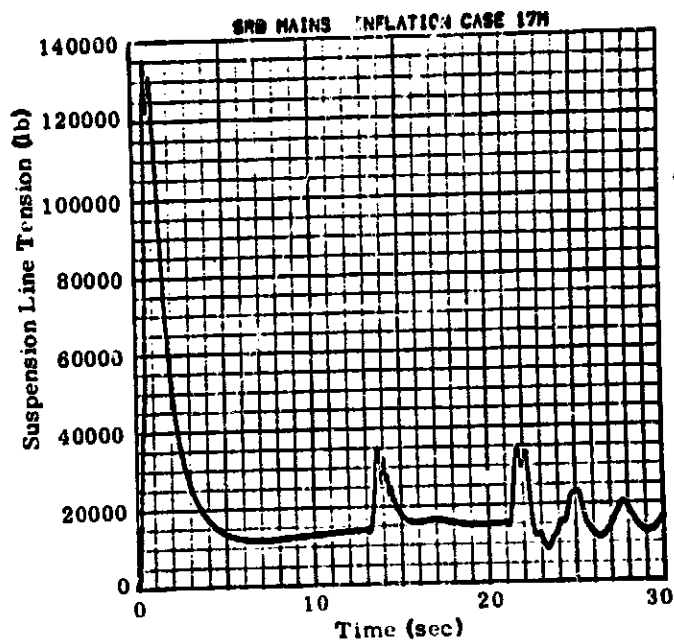
MAIN CHUTE DROP TEST LOADS -
## DESIGN LOAD ON ALL CLUSTER STAGES

Drop conditions required to subject all three stages of the main chute cluster to design load were investigated. It is clear from the previous simulation that shorter reefing times are required to load all three stages. Also, going to a higher altitude and a vertical trajectory are helpful. The first figure shows that for a horizontal drop at an initial altitude of 40,000 feet and a dynamic pressure of 169 lb/ft^2, near design loads were obtained on all three cluster stages. Very short reefing times of 2 seconds and 1 second were used. The second figure shows that for a vertical deployment at the same altitude and dynamic pressure and using the same reefing times, design load is obtained or exceeded on all three stages. Based on this analysis it would appear that in theory at least, design loads could be obtained on all three stages of the main chute cluster by deploying at high altitudes and using very short reefing times. In practice, however, serious objections to this test method can be raised. The short reefing times probably demand greater accuracy in predicted inflation times than has been demonstrated by the inflation model being used. Also, tolerances in reefing cutter time delays could cause unacceptable unequal loadings in individual cluster chutes. This test method is therefore not recommended without additional study.

MAIN CHUTE DROP TEST LOADS -
DESIGN LOAD ON ALL CLUSTER STAGES

Vertical Trajectory
$q = 169 \text{ lb/ft}^2$
$h = 40,000$ feet
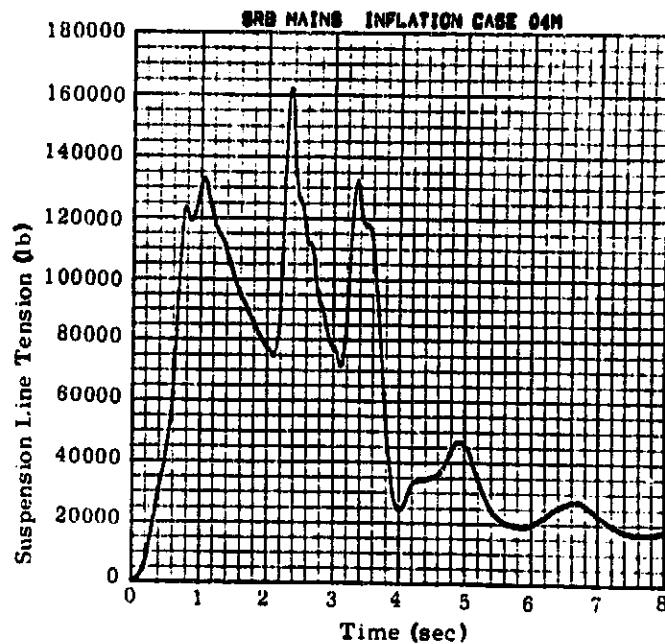
SRB MAINS INFLATION CASE 04M

Horizontal Trajectory
$q = 169 \text{ lb/ft}^2$
$h = 40,000$ feet

SRB MAINS INFLATION CASE 05M
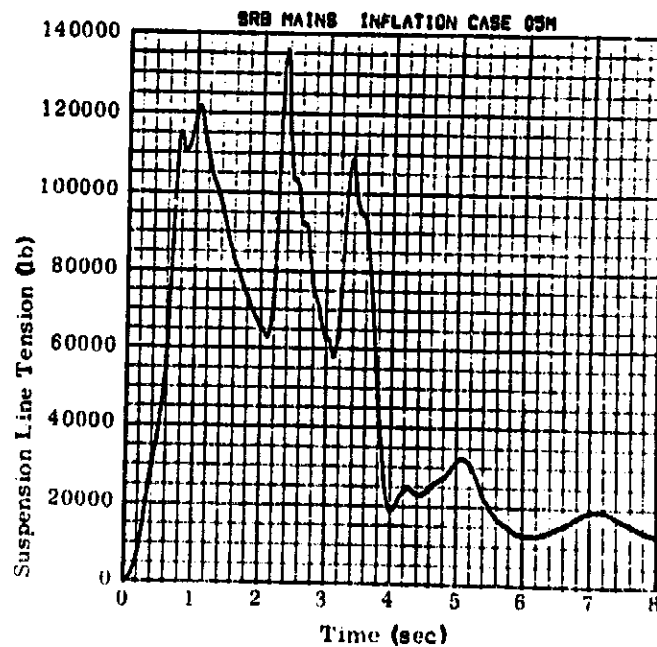
MAIN CHUTE DROP TEST LOADS -
SINGLE CHUTE TESTS, VERTICAL TRAJECTORY

The difficulty in subjecting the main chute cluster to design loads has been illustrated by the previous examples. It is much easier to subject a single main chute to design loads or even an overload condition. By deploying a single main chute from a 50,000 pound test vehicle in a vertical trajectory at an altitude of 20,000 feet, design loads on all three stages can be obtained. Slightly shortened reefing times of 10 seconds and 6 seconds and a nominal initial dynamic pressure of 147 lb/ft^2 were used. By increasing the initial dynamic pressure to 220 lb/ft^2, a 30 percent overload on the main chute first stage is obtained.

MAIN CHUTE DROP TEST LOADS -
SINGLE CHUTE TESTS, VERTICAL TRAJECTORY

SRB MAINS   INFLATION CASE 06M

SRB MAINS   INFLATION CASE 07M
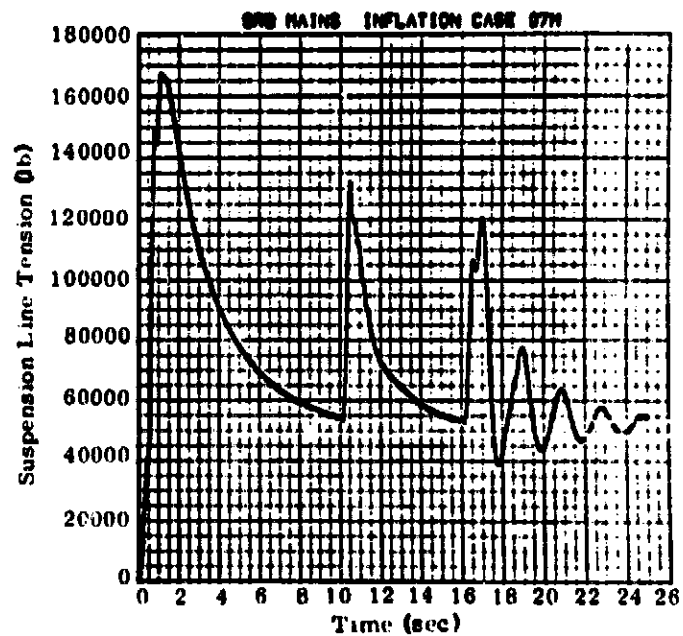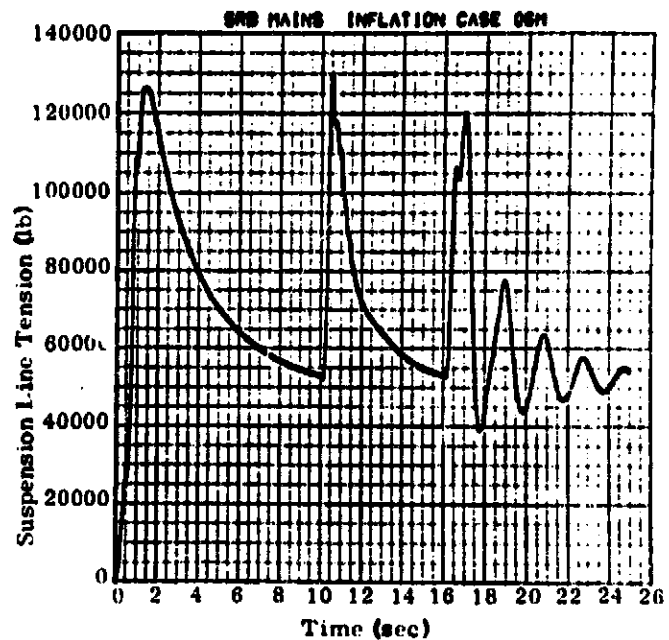
MAIN CHUTE DROP TEST LOADS -
SINGLE CHUTE TESTS, HORIZONTAL TRAJECTORY

Design loads on a single main chute can also be achieved using the simpler horizontal deployment. Assuming the same configuration as in the previous example, but deployed in a horizontal trajectory, design loads on all three stages are obtained for an initial dynamic pressure of 160 lb/ft^2. Reefing times were shortened to 4 seconds and 2 seconds. Overloads on the first two stages were obtained for an initial dynamic pressure of 225 lb/ft^2.

MAIN CHUTE DROP TEST LOADS -
SINGLE CHUTE TESTS, HORIZONTAL TRAJECTORY

ORB MAINS INFLATION CASE 20M

Design Load
$q = 160 \, lb/ft^2$

Suspension Line Tension (lb) vs Time (sec)

ORB MAINS INFLATION CASE 22M

Overload
$q = 224 \, lb/ft^2$

Suspension Line Tension (lb) vs Time (sec)
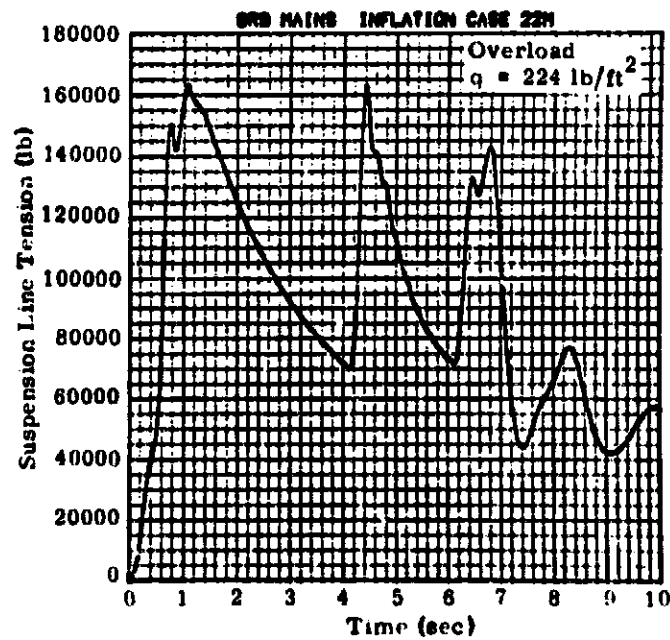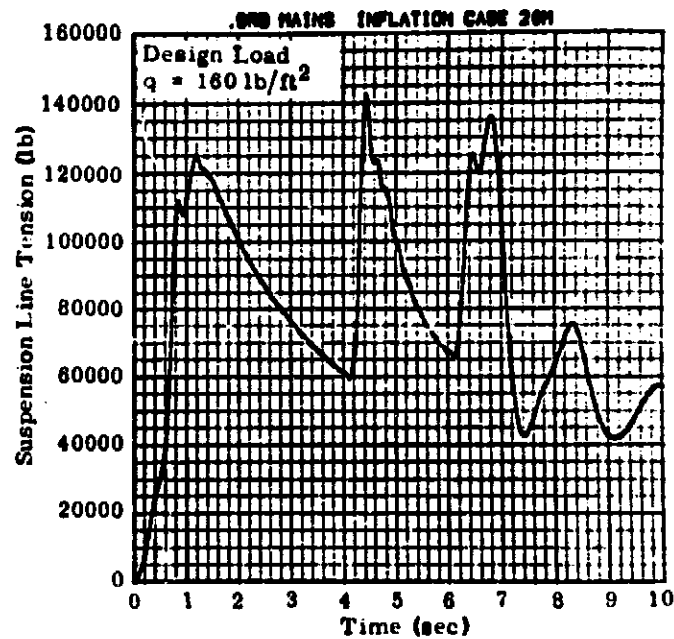
MAIN CHUTE DROP TEST LOADS -
SINGLE CHUTE TESTS, HORIZONTAL TRAJECTORY, HIGH ALTITUDE

Design and overload tests on a single chute could also be run at a higher altitude using longer reefing times. A horizontal deployment at 40,000 feet and a dynamic pressure of 160 lb/ft^2 results in design load on all three stages using reefing times of 6 seconds and 4 seconds. By increasing the initial dynamic pressure to 208 lb/ft^2 and using reefing times of 6 seconds and 2 seconds, 30 percent overloads on all three stages are possible.

MAIN CHUTE DROP TEST LOADS -
SINGLE CHUTE TESTS, HORIZONTAL TRAJECTORY, HIGH ALTITUDE

SRB MAINS   INFLATION CASE 18M

Design Load
$q = 160 \text{ lb/ft}^2$

SRB MAINS   INFLATION CASE 18M

Overload
$q = 208 \text{ lb/ft}^2$
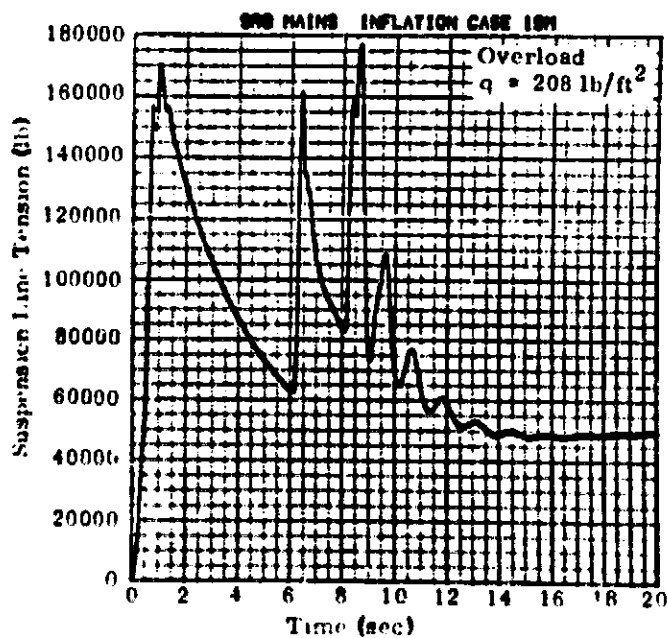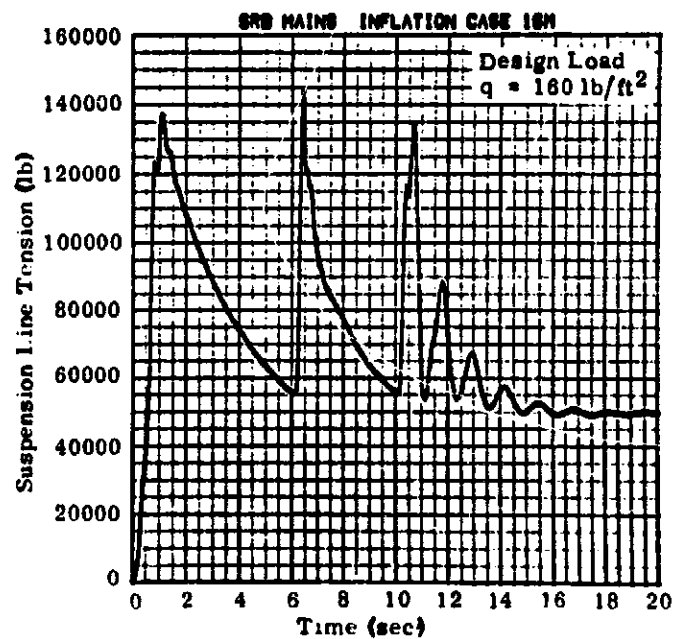
THEORETICAL STORE SEPARATION ANALYSIS FOR
SRB PARACHUTE TEST UNIT

The theoretical store separation analysis proposed to support the drop test program using SRB Parachute Test Units dropped from the wing pylon of the B-52 Mother Ship is defined on subsequent pages of this section. This theoretical store separation analysis has four distinct purposes.

The first purpose is to define the store separation characteristics of the SRB Parachute Test Unit from the B-52 early in the program. This will allow any necessary changes to be accomplished with minimum costs and minimum schedule slippages.

The second purpose is to help define the need for any store separation wind tunnel tests required for the SRB Parachute Test Unit and the B-52. If the theoretical store separation analysis shows the SRB Parachute Test Unit separates without any problems, the need for store separation wind tunnel tests might be eliminated. Conversely, if the theoretical analysis indicates store separation problems may exist, the results would provide justification for establishing a store separation wind tunnel test program.

The third purpose is to define the aerodynamic carriage loads on the SRB Parachute Test Unit during carriage on the Mother Ship early in the program. This information is needed to verify the structural adequacy of the SRB Parachute Test Unit.

The fourth purpose is to provide the necessary documented pre-flight analyses to obtain approval from the Air Force and NASA to drop the SRB Parachute Test Unit from the Mother Ship. This documentation would describe and present the results of the store separation and carriage loads analyses described in the preceding paragraphs.

PURPOSES OF THEORETICAL STORE SEPARATION ANALYSIS

1. DEFINE STORE SEPARATION CHARACTERISTICS OF SRB PARACHUTE TEST UNIT FROM B-52 MOTHER SHIP EARLY.

2. DEFINE WHETHER STORE SEPARATION WIND TUNNEL TESTS ARE NEEDED.

3. PROVIDE THEORETICAL AERODYNAMIC CARRIAGE LOADS FOR SRB PARA-CHUTE TEST UNIT FOR SEVERAL PERTINENT B-52 FLIGHT CONDITIONS.

4. PROVIDE DOCUMENTATION OF THEORETICAL STORE SEPARATION AND CARRIAGE LOADS PREFLIGHT ANALYSES TO OBTAIN APPROVAL TO DROP SRB PARACHUTE TEST UNITS FROM B-52 MOTHER SHIP.

THEORETICAL STORE SEPARATION COMPUTER PROGRAM

The use of theoretical store separation analyses in preliminary design can supplement and, hopefully, reduce the number and magnitude of wind tunnel and flight drop tests. A computer program (5-1, -2) was developed by Nielsen Engineering and Research, Inc. to compute the theoretical separation trajectory of an external store released from an aircraft flying at subsonic speeds. This computer program would be used for the theoretical store separation analysis for the SRB.

The aircraft fuselage, separated store body, and nacelles, fuel tanks, and the bodies of other stores carried are modeled using point sources and sinks distributed along the centerlines of the bodies. In addition, multipoles are used to include the effects of any nonaxisymmetric geometry for the aircraft fuselage.

The computer program first calculates the forces and moments acting on the store in the carriage position in the nonuniform flow field below the aircraft. Then, the computer program uses 6 degree-of-freedom trajectory calculations to compute the motion of the store for a small time interval. The forces and moments acting on the store are computed at the new position, and the procedure is repeated until the separated store has traversed the nonuniform flow field near the aircraft.

Reference 6-3 describes how theoretical calculations (5-4, -5) of the pitching and yawing moments were made by NASA for the X-15 during carriage on the B-52 Mother Ship. Quoting Reference 5-3, "Since the mathematical model used to calculate the flow field for the B-52 wing was sufficient to allow calculations that are in close agreement with experiment . . . the loads and moments for other vehicles for which the B-52 might be used as a carrier could probably be estimated with sufficient accuracy to determine the necessity for, and aid in the interpretation of, wind-tunnel tests."

As the theoretical store separation computer program can use a more complete mathematical model for the B-52 than was used in the results in Reference 3, one would expect the results to agree with wind tunnel or flight data at least as well as the theoretical results and flight data agreed in Reference 3.

NIELSEN/AFFDL THEORETICAL STORE
SEPARATION TRAJECTORY COMPUTER PROGRAM

PURPOSE - COMPUTE THE THEORETICAL CARRIAGE LOADS AND STORE SEPARATION
TRAJECTORY OF A STORE CARRIED AND RELEASED FROM AN AIRCRAFT FLYING
AT SUBSONIC (SUBCRITICAL) SPEEDS.

AIRCRAFT FUSELAGE MODEL - UP TO 100 SOURCES AND SINKS (FOR FUSELAGE
VOLUME DISTRIBUTION). UP TO 1,000 MULTIPOLES (FOR FUSELAGE NON-
AXISYMMETRIC GEOMETRY.

AIRCRAFT WING MODEL - INCLUDES CAMBER, TWIST, DIHEDRAL, SWEEPBACK,
AND THICKNESS; UP TO 160 YAWED HORSESHOE VORTICES, 800 THICKNESS
STRIPS, AND 160 POINTS DEFINING CAMBER AND TWIST.

AIRCRAFT PYLON MODEL - INCLUDES THICKNESS AND SWEEPBACK. (USES YAWED
HORSESHOW VORTICES AND THICKNESS STRIPS, LIKE WING MODEL.)

AIRCRAFT RACK MODEL - AXISYMMETRIC BODY; UP TO 100 SOURCES AND SINKS.

RELEASED STORE BODY MODEL - AXISYMMETRIC BODY; UP TO 100 SOURCES AND
SINKS.

OTHER STORES, NACELLES, AND FUEL TANKS - UP TO 9 AXISYMMETRIC BODIES;
UP TO 100 SOURCES AND SINKS FOR EACH BODY.

COST - APPROXIMATELY ONE MILLION DOLLARS. (APPROXIMATELY ONE-HALF
OF COST IS FOR WIND TUNNEL TESTS TO CHECK THE ACCURACY OF THE
PROGRAM.)

TIME REQUIRED - DEVELOPMENT STARTED APPROXIMATELY 1970.

DOCUMENTATION - LANGLEY PROGRAMS (USED IN NIELSEN/ AFFDL COMPUTER
PROGRAM)   - 156 PAGES
3 DEGREE-OF-FREEDOM VERSION   - 282 PAGES
6 DEGREE-OF-FREEDOM VERSION   - 801 PAGES

TOTAL - 1,239 PAGES

SANDIA-DEVELOPED SUPPLEMENTAL THEORETICAL STORE SEPARATION COMPUTER PROGRAMS

Sandia Laboratories has developed several supplemental store separation computer programs. These supplemental computer programs are used to rapidly and economically prepare the complex aircraft configuration and store geometry data required as input for the theoretical store separation computer program.

The facing page summarizes three of these computer programs. Additional information on computer program SOURCE is available in Reference 5-6.

SANDIA-DEVELOPED SUPPLEMENTAL THEORETICAL
STORE SEPARATION COMPUTER PROGRAMS

<u>FUSLAG</u> - COMPUTES EQUIVALENT AXISYMMETRIC FUSELAGE GEOMETRY.

<u>WINGO1</u> - COMPUTES WING THICKNESS AND PYLON THICKNESS INPUT DATA
REQUIRED.

<u>SOURCE</u> - COMPUTES SOURCE AND SINK DISTRIBUTIONS TO MODEL AXISYM-
METRIC BODIES. OPERATIONAL ON SLA INTERACTIVE GRAPHICS
SYSTEM. COMPRESSES TWO WEEKS' CALENDAR TIME WORK INTO
ONE HOUR'S WORK ON GRAPHICS TERMINAL.

VISUAL DOCUMENTATION COMPUTER PROGRAM

A permanent visual documentation system has been developed by Sandia Laboratories to provide rapidly and economically visual documentation of theoretical store separation analyses. The documentation system uses a new Sandia Laboratories computer program (MOVIE) with a CDC 6600 computer to generate a magnetic tape of plotting commands for an off-line modified DatagraphiX 4020 plotter.

The major features of the visual documentation computer program are summarized on the facing page. (Additional information on the visual documentation computer program is available in Reference 5-7 and 5-8.)

Sample output from the visual documentation computer program are presented later in this section of the report. The computer time required to generate slides or drawings for a store separation is a fraction of a minute. The computer time required to generate a color movie for a store separation is approximately 5 minutes.

VISUAL DOCUMENTATION COMPUTER PROGRAM, MOVIE 1

- PRESENTS SIDE AND BOTTOM VIEWS OF STORE SEPARATION PROCESS.

- PREPARES VISUAL DOCUMENTATION USING ALL OUTPUT MEDIA AVAILABLE ON A MODIFIED DATAGRAPHIX 4020 PLOTTER.

- COMPUTER TIME SAVED BY:

    1. NOT SHOWING ROLL ORIENTATION OF STORE.

    2. USING LINEAR INTERPOLATION WITH TIME ON STORE POSITION.

    3. STORING OF REPETITIVELY USED PLOT COMMANDS.

- COMPUTER CODE WRITTEN IN FORTRAN.

- PLOT COMMANDS GENERATED USING SCORS PLOT SUBROUTINES.

MODIFIED DATAGRAPHIX PLOTTER

The visual documentation for the theoretical store separation analysis results are prepared on a modified DatagraphiX 4020 plotter. The output media available include pictures, slides, and movies. The slides and movies can be generated in black and white or color.

Further details on the output media available for the visual documentation of the theoretical store separation analysis results are available on the facing page.

MODIFIED DATAGRAPHIX 4020 PLOTTER

- MODIFIED WITH EIGHT SEGMENT COLOR WHEEL (WHITE, CYAN, GREEN, MAGENTA, RED, YELLOW, BLUE, AND LIGHT BLUE).

- HAS SPECIAL COLOR SENSITIVE PHOSPHORUS MIX ON CATHODE RAY TUBE.

- HAS THE FOLLOWING OUTPUT MEDIA:

    7-1/2 INCH BY 7-1/2 INCH HARD COPY (BLACK AND WHITE ONLY).

    16-MM MOVIES (BLACK AND WHITE AND COLOR).

    35-MM SLIDES (BLACK AND WHITE AND COLOR).

    35-MM MOVIES (BLACK AND WHITE AND COLOR).

- BLACK AND WHITE OUTPUT MEDIA ARE AVAILABLE BY 8 AM FOR RUNS SUB-MITTED TO COMPUTER BY 5 PM OF PRECEDING DAY.

COMPARISON OF THEORY WITH FULL SCALE DROP TEST RESULTS

In order to assess the accuracy of the theoretical store separation computer program, a comparison was made between predicted results and the results of a full-scale flight drop test. The Sandia Laboratories prototype store is a canard-controlled store approximately 140 inches long with a maximum diameter of approximately 15 inches. The store weight is approximately 850 pounds, and its center of gravity is located approximately 85 inches rearward from the nose. The F-4D aircraft configuration used for the drop test and the theoretical calculations is gear up, flaps up, and dive breaks up (i.e., clean). The prototype store was carried on one inboard pylon, using an adapter.

The detailed comparison of the calculated and observed results is provided in Reference 6-9. Briefly, examination of the theoretical and observed vertical displacement histories shows excellent agreement. The differences between the two curves approach the accurach of the observed data. The vertical displacement histories are obviously the data of most interest to the drop aircraft pilot. (The most probable cause of the differences in the theoretical and experimental results is canard lag, which would not have been defined in any wind tunnel store separation tests.) In summary, good agreement is shown between the theoretical and observed store separation trajectories, especially during the first critical half cycle of the store separation.
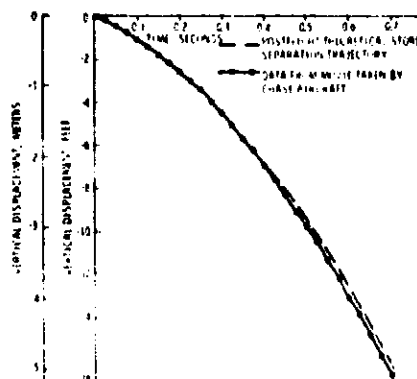
Theoretical and Observed Canard Position Prior to Drop

Canard Number	Theoretical Canard Position (degrees)	Observed Canard Position (degrees)
1	+0.2	-0.5
2	+3.3	+3.4
3	-0.2	+0.2
4	-3.3	-3.4
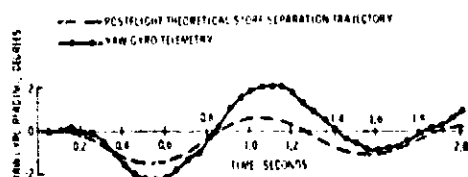
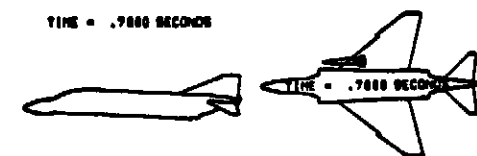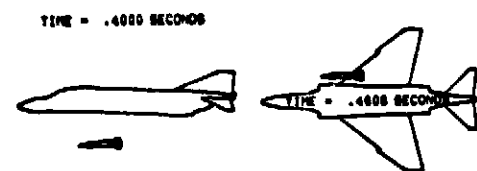Comparison of Postflight Predicted and Observed Yaw Gyro Reading Histories
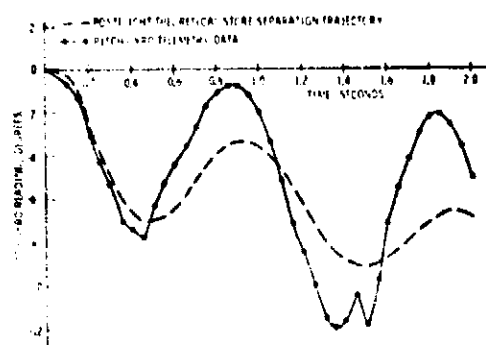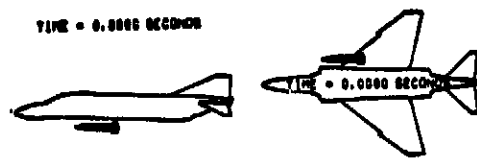

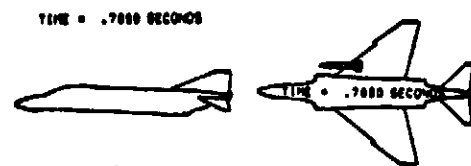Comparison of Postflight Predicted and Observed Pitch Gyro Reading Histories
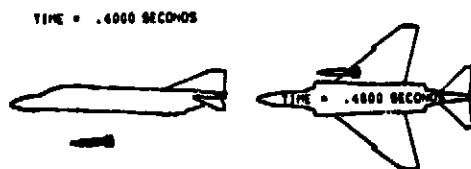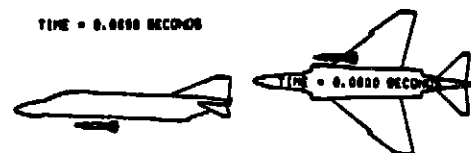

Comparison of Postflight Predicted and Observed Store Center of Gravity Vertical Displacement Histories

COMPARISON OF THEORY WITH FULL SCALE DROP TEST RESULTS

TIME = 0.0000 SECONDS

TIME = 0.0000 SECONDS

TIME = .4000 SECONDS

TIME = .4000 SECONDS

TIME = .7000 SECONDS

TIME = .7000 SECONDS

Prototype Store Ejected from F-4D
at Mach 0.70, 15,000 Feet Altitude
— Canards Free-Floating

TIME = 0.0000 SECONDS

TIME = 0.0000 SECONDS

TIME = .5000 SECONDS

TIME = .5000 SECONDS

TIME = .9000 SECONDS

TIME = .9000 SECONDS

Prototype Store Ejected from F-4D
at Mach 0.70, 15,000 Feet Altitude
— Canards Full Up at Ejection

TIME = 0.0000 SECONDS

TIME = 0.0000 SECONDS

TIME = .4000 SECONDS

TIME = .4000 SECONDS

TIME = .7000 SECONDS

TIME = .7000 SECONDS

Prototype Store Ejected from F-4D
at Mach 0.70, 15,000 Feet Altitude
— Canards Fixed at Zero Deflection

THEORETICAL CARRIAGE LOADS AND STORE SEPARATION ANALYSES
FOR SRB PARACHUTE TEST UNIT

As the SRB Parachute Test Unit is not defined, it is difficult to estimate the costs for the theoretical carriage loads and store separation analysis described in the preceding sections of this report. However, the following estimates are provided to define approximately the costs of the analyses.

The costs estimated below assume that the SRB Parachute Test Unit will have a reasonable aerodynamic static margin and that the shape can be analyzed using the theoretical store model in the computer program. However, the costs estimated below are also reasonable if the SRB Parachute Test Unit has a nonconventional shape or relatively small static margin if the experimental free-stream aerodynamics of the Parachute Test Unit are available (at no cost to the store separation analaysis).

The adajacent page shows the steps required for the theoretical store separation analysis. By each step, the required calendar time and estimated man-months required are shown. Since the steps are serial, the time required from start of the program can be obtained for any step by summing all the calendar time required.

The three man-months shown would cost approximately $13,500. The estimated computer time required is approximately 10 hours at a cost of approximately $3000. Estimated travel costs, to obtain geometry data on B-52 and SRB Parachute Test Unit and present the results of the analysis, are $750.

Thus, the total cost of the theoretical carriage loads and theoretical store separation analyses would be approximately $17,250.

Any questions about the proposed theoretical store separation and theoretical carriage loads analyses should be addressed to:

Harold R. Spahr - 5625
Sandia Laboratories
P. O. Box 5800
Albuquerque, New Mexico 87115

(Telephone 505-264-4854)

THEORETICAL CARRIAGE LOADS AND STORE SEPARATION ANALYSES
FOR SRB PARACHUTE TEST UNIT

STEPS IN ANALYSIS	CALENDAR MONTHS	MAN MONTHS
OBTAIN GEOMETRY FOR B-52 MOTHER SHIP.	1.00	0.50
DEVELOP THEORETICAL MODEL OF B-52 MOTHER SHIP.	2.00	1.00
DEVELOP THEORETICAL MODEL OF SRB PARACHUTE TEST UNIT.	0.50	0.25
SET UP AND CHECK OUT COMPLETE STORE SEPARATION AND CARRIAGE LOADS INPUT DECK.	0.50	0.25
COMPUTE CARRIAGE LOADS AND STORE SEPARATION TRAJECTORIES FOR FLIGHT CONDITIONS OF INTEREST.	1.00	0.50
DOCUMENT IN MEMO (LETTER) FORM THE RESULTS OF THE THEORETICAL CARRIAGE LOADS AND THEORETICAL STORE SEPARATION ANALYSES.	1.00	0.50
	6.00	3.00

REFERENCES

1. Marnix F. E. Dillenus, Frederick K. Goodwin, and Jack N. Nielsen, "Extension of the Method for Predicting Six-Degree-of-Freedom Store Separation Trajectories at Speeds Up to the Critical Speed to Include a Fuselage With Noncircular Cross Section - Vol. I - Theoretical Methods and Comparisons With Experiment," draft copy of unnumbered Air Force Flight Dynamics Laboratory Technical Report. March 1974. (Available from C. F. Dyer, AFFDL.)

2. Frederick K. Goodwin and Marnix F. E. Dillenus, "Extension of the Method for Predicting Six-Degree-of-Freedom Store Separation Trajectories at Speeds Up to the Critical Speed to Include a Fuselage with Noncircular Cross Section - Vol. II - Users Manual for the Computer Programs, draft copy of unnumbered Air Force Flight Dynamics Laboratory Technical Report, March 1974. (Available from C. E. Dyer, AFFDL.)

3. William J. Alford, Jr., and Robert T. Taylor, "Aerodynamic Characteristics of the X-15/B-52 Combination," Nasa Memorandum 6-8-59L, June 1959.

4. William J. Alford, Jr., "Theoretical and Experimental Investigations of the Subsonic-Flow Fields Beneath Swept and Unswept Wings With Tables of Vortex-Induced Velocities, NACA Report 1327, 1957.

5. D. A. Heydon, D. L. Jones, and W. F. Sheehan, "Subsonic Flow Fields and Induced Missile Loads in the Vicinity of Non-Lifting and Lifting Wing-Pylon Combinations," Sperry Report No. 42s-1502, Sunnyvale Development Center, Sperry Gyroscope Co., December 1957.

6. Harold R. Spahr and Hugh A. Sumlin, "Interactive Computer Graphics Applied to the Interactive Aircraft/Store Separation Problem," a paper presented at the conference on Computer Graphics and Interactive Techniques (sponsored by the University of Colorado Computing Center and the Association of Computing Machinary Special Interest Group on Graphics) at Boulder, Colorado, July 15-17, 1974.

7. Harold R. Spahr, "Computer Generated Visual Documentation of Theoretical Store Separation Analyses," Aircraft/Stores Compatibility Symposium Proceeding, Volume 2, page 208, January 1974, sponsored by JTCG/ALNNO, held at Sacramento, California on September 18-20, 1973.

8. Harold R. Spahr, "Computer Generated Visual Documentation of Theoretical Store Separation Analyses," Proceedings of the Technical Program, page 30, May 1974, Second Annual ACM SIGGRAPH Computer Information Exchange Meeting (Theme: Computer Graphics), Association of Computing Machinaries, held in New York City, New York on May 2-3, 1974.

9. Harold R. Spahr, "Theoretical Store Separation Analysis of a Prototype Store and Comparison with Flight Drop Test," AIAA Paper 74-776, presented at the AIAA Mechanics and Control of Flight Conference at Anaheim, California, August 5-9, 1974.

DISTRIBUTION:

5626   D. F. Wolf (50)
8266   E. A. Aas (2)
3141   L. S. Ostrander (5)
3151   W. F. Carstens (3) For ERDA/TIC (Unlimited Release)